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Is it credit or liquidity risk, or both?

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LIQUIDITY CRUNCH IN THE INTERBANK MARKET: IS IT CREDIT OR LIQUIDITY RISK, OR BOTH?

Angelo Baglioni

Abstract. *The interplay between liquidity and credit risks in the interbank market is analyzed. Banks are hit by idiosyncratic random liquidity shocks. The market may also be hit by a bad news at a future date, implying the insolvency of some participants and creating a lemon problem; this may end up with a gridlock of the interbank market at that date. Anticipating such possible contingency, banks currently long of liquidity ask a liquidity premium for lending beyond a short maturity, as a compensation for the risk of being short of liquidity later and being forced to liquidate some illiquid assets. Then banks currently short of liquidity may prefer to borrow short term. The model is able to explain some stylized facts of the 2007-2009 liquidity crunch affecting the money market at the international level: (i) high spreads between interest rates at different maturities; (ii) "flight to overnight" in traded volumes; (iii) ineffectiveness of open market operations, leading the central banks to introduce some relevant innovations into their operational framework.*

Keywords. Global financial crisis, Money market, Liquidity, Central banking.

JEL Codes: G01, G21, E43, E50.

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1 Introduction

The liquidity crunch taking place in the interbank market during the 2007-2009 international financial turmoil raises some puzzling questions:

- why did the spread between the medium term and the short term (say three month – overnight) interest rates jump to unprecedented levels?

- why did the trading activity dry up in those market segments with maturities longer than very short term (so called "flight to overnight")?

- why did these phenomenons occur and persist for a long time despite the massive injections of liquidity by the central banks of several countries (often coordinated through swap agreements)?

There is a wide empirical evidence documenting the stylized facts summarized in the above three questions – and some additional evidence for the euro area is provided in the Appendix. See Cecchetti (2009), Taylor - Williams (2008), and Ashcraft - McAndrews - Skeie (2008) for the U.S.; Heider - Hoerova - Holthausen (2009), Eisenschmidt - Tapking (2009), and ECB (2009, a) for the euro area.

The present work tries to give a theoretical contribution in explaining this puzzle. The starting point is that we have to find an explanation by looking at the interplay between credit and liquidity risks. Those models focussing on a single source of risk are not able to provide a satisfactory answer[1]. If liquidity were the only relevant variable, central banks should have been able to rapidly restore normal conditions in the interbank market, by injecting huge amounts of liquidity and making the supply of bank reserves meet the level demanded by the banking system. If credit risk were the only relevant variable, it would be hard to explain the remarkable differences across market segments, in particular why the short term segment has been rather immune from the crunch: why should a bank be ready to lend short term at normal rates to another bank, if she believes that the counterparty might not be able to repay?

In our approach, banks face two risks at the same time.

Liquidity risk: a bank hit by a liquidity shock is uncertain whether such a shock is going to be "permanent" (lasting for two periods) or "transitory" (lasting for one period only). As a consequence, if a bank with an excess liquidity lends it long term, she undertakes the risk of being short of liquidity in the future: if the initial positive shock turns out later to be transitory

[1] Models applying the Diamond - Dybvig (1983) approach generally focus on liquidity risk (see the references in the next section). Alternatively, Flannery (1996) focusses on credit risk under asymmetric information, showing how adverse selection may lead to a break down of the interbank market.

– making the excess liquidity vanish – such a bank will have to borrow in the interbank market to fund the long term loan. The liquidity risk has become more relevant during the financial turmoil, due to a higher volatility of liquidity shocks. A factor contributing to this volatility is the complexity of financial conglomerates together with the sudden freezing of some segments of the money market: for example, a vehicle unable to roll-over an outstanding issue of asset-backed commercial paper may draw on the bank credit line supporting such an issue. An indicator of liquidity (funding) risk is the behavior of banks participating in monetary policy operations: the evidence reported in the Appendix shows a more aggressive behavior in open market operations, pointing to an increased funding risk during the financial crisis.

Credit risk: the interbank market may be hit by a negative shock in the future, implying that some participants suffer losses so large to become insolvent. The distribution of those losses is private information, implying an adverse selection problem. The globalization of financial markets plays a key role under this regard: a bad news affecting a large player can have a significant impact on market participants in other countries, due to the network of exposures at the international level. More broadly, this assumption captures the idea that – during a financial crisis – market participants fear a sudden worsening of the adverse selection typically affecting a credit market with asymmetric information.

The interplay between these two sources of risk does not have any striking implications as long as the adverse selection problem is not too severe. In this case, the only consequence is that a credit risk premium must be incorporated into the interbank interest rates. The liquidity risk does not have any dramatic consequence, since banks are confident that they will be able to raise liquidity in the future if they need to do so (in order either to fund a long term interbank loan or to roll-over a short term interbank debt).

Things get much worse if the possible adverse selection problem is so severe to make the interbank market dry up. This gridlock is not surprising *per se*: the drop of trades in a market affected by an adverse selection problem is a standard result in agency theory. However it bears some interesting implications for the equilibrium of the interbank market *before* such breakdown may possibly occur. Banks now take into account the chance that the interbank market may no longer be there in the near future, forcing those banks short of liquidity at that time to liquidate illiquid assets and suffer significant liquidation costs. Hence banks currently long of liquidity ask a liquidity premium on a long term interbank loan, as a compensation for the expected liquidation cost. Two alternative situations may then arise. (i)

Banks currently short of liquidity are ready to pay such liquidity premium, in order to avoid the roll-over risk incurred by borrowing short term. (ii) If the (lowest possible) liquidity premium required by lending banks is too high, banks currently short of liquidity prefer to borrow short term. The latter alternative prevails if liquidity shocks are more likely to be transitory than permanent.

The model is able to provide some tentative answers to the questions raised at the beginning of this Introduction. First, the chance of a gridlock of the interbank market in the future adds a relevant component to the spread between medium and short term interbank rates, by introducing a liquidity premium. Second, if the volatility of liquidity shocks is high enough − which was presumably the case during the financial turmoil − the liquidity premium on longer maturities gets so large that banks needing to raise liquidity prefer to borrow on shorter maturities: this provides an explanation for the "flight to overnight". Finally, the key ingredients leading to the above results are the volatility of idiosyncratic liquidity shocks and credit risk, while no aggregate shortage of liquidity ever comes into the picture: by definition, the management of the aggregate liquidity supply by the central bank does not play an explicit role in this context.

The plan of the paper is the following. After a brief review of the related literature (Section 2), the model is illustrated in Section 3. Some policy implications are derived in Section 4, and the main insights of the analysis are summarized in Section 5. Finally, the Appendix documents some stylized facts supporting the predictions of the model.

2 Related literature

The theory of banking has for a long time built on the seminal contribution by Diamond - Dybvig 1983 (DD). The key insight of the DD framework is that banks insure consumers against liquidity risk. Since they invest only a fraction of deposits in liquid reserves, banks bear the risk of being short of liquidity in some contingencies, including a coordination failure among retail depositors ("bank run"). This approach has generated a wide literature (surveyed in Allen - Gale 2007), and it has been applied to the analysis of the interbank market; see for example Bhattacharya - Gale (1987), Allen - Gale (2000), and Freixas - Martin - Skeie (2009).

However, there is quite a strong evidence that the global liquidity crunch, starting in August 2007, was not triggered by retail depositors, even in those cases where they might appear to be responsible for that (e.g. Northern Rock). To the contrary, the hoarding behavior of financial institutions played a crucial role, making liquidity dry up in the money market. Banks more relying on wholesale (international) markets for their funding were the more prone to a liquidity squeeze, contrary to those more relying on retail deposits[2]. See Shin (2009), Brunnermeier (2009), and Ashcraft - McAndrews - Skeie (2008).

Therefore several recent studies abstract from retail deposits and focus on wholesale money markets. Huang - Ratnovski (2008) extend the Calomiris - Kahn (1991) framework to show that short term wholesale financiers can force an inefficient liquidation of bank assets. The same issue was tackled even before the recent crisis by Rochet - Vives (2004), pointing to the coordination failure among large CD holders. Acharya - Gale - Yorulmazer (2009) show that the release of information may cause the market for asset-backed securities to dry up. Adrian - Shin (2009) and Brunnermeier - Pedersen (2008) study the mechanisms amplifying the impact of a (small) shock to the balance sheet of financial intermediaries ("loss spirals" and "margin spirals"). This growing body of literature generally studies the market for short term bank liabilities − including repos and commercial paper − held by non-bank financial institutions, like mutual and hedge funds. My paper shares with this literature the attention paid to the incentives and constraints faced by players in the money market, abstracting from the behavior of retail depositors. However my focus is on the role of the unsecured interbank market, where banks trade their reserves in response to idiosyncratic liquidity shocks.

A couple of papers are very close to mine, as they deal with the interaction between liquidity and credit risk in the interbank market. Let me expand on them.

The key element in Eisenschmidt - Tapking (2009) is the risk, faced by a lender in the interbank market, that his creditworthiness may eventually worsen, making his cost of funding rise. This risk explains the liquidity premium charged on interbank loans and it possibly makes the traded volumes in the long term market drop to zero. Differently from mine, their model crucially rests on the existence of a secured interbank market, providing an alternative source of funding. Moreover, they do not introduce any informational issue possibly leading to a gridlock of the interbank market. They assume instead that in the short term unsecured market − and in the secured market on all maturities as well − trades always take place at an

[2] The huge amount of wholesale short term funding in foreign currency has been at the origin of the Icelandic banking crisis. See Buiter - Sibert (2008).

exogenous interest rate.

The model by Heider - Hoerova - Holthausen (2009) is still within the DD framework. Banks are uncertain about the number of their "impatient" depositors and about the riskiness of their illiquid assets. The interbank market may break down because of adverse selection: in such a case, banks short of liquidity need to liquidate part of their illiquid assets. The main difference with my approach (apart from methodological issues) is that they do not consider an interbank market with different maturities; then by definition their model is unable to explain the emergence of high spreads between interest rates at different maturities as well as the so-called "flight to overnight". In addition, their analysis is limited to the break-down taking place in the interbank market at the time where an adverse selection problem emerges; to the contrary, my model stresses the impact of a gridlock *before* it can actually occur.

Finally, there is a growing empirical literature related to this paper, trying to measure the two risk premia − credit and liquidity − incorporated in money market spreads since August 2007. It is difficult to say which of the two items prevails: while some authors provide evidence that credit risk is predominant (an example is Taylor - Williams 2008), others stress the importance of liquidity risk (an example is Eisenschmidt - Tapking 2009). The role of liquidity is documented also by those studies focussing on the intraday patterns of traded volumes and of interest rates in the interbank market (see Hansal - Jackson - Merrouche 2008, and Baglioni - Monticini 2008 a,b). Overall, the evidence shows that both elements play a relevant role, supporting the view - taken here - that we should look at the interplay between the two sources of risk.

3 The model

3.1 Set-up

Let us consider a banking system where each bank is endowed with 1 unit of retail deposits invested in loans[3]. All agents in the economy are risk-neutral.

[3]The assumption that all banks enter the model without any liquid reserves needs to be justified. The rationale behind this assumption is that, for any target level of liquid reserves, a bank may be hit either by a positive shock, creating excess (undesired) reserves, or by a negative shock exceeding available reserves. Then a bank, with a positive target level of liquid reserves, may turn out to be either long or short of liquidity, due to random shocks. We are not interested here in determining *ex ante* the optimal target level of reserves, but rather in how an *ex post* shortage or excess of liquidity is managed

There are three dates: $t = 0, 1, 2$. Retail deposits are repaid at $t = 2$, and they are fully insured through a fairly priced deposit insurance scheme[4]. Thus banks pay the riskless rate of interest on deposits. These assumptions capture the fact that retail deposits are a stable source of funding, due to the passive behavior of depositors, even during a financial turmoil like the one taking place in 2007-2008 (see the discussion in the previous section). Of course, this passive behavior rests on the safety net supporting the banking system, which is introduced here in a stylized way through the deposit insurance. Needless to say, the insurance does not cover the interbank loans.

The focus of this paper is not on aggregate liquidity, which can be managed by the central bank through the usual tools (open market operations). Therefore I assume that there never is any liquidity shortage for the banking system as a whole. As a consequence, there is competition among lenders in the interbank market, where lenders' reservation price is the riskless rate of interest: they demand an expected return on an interbank loan weakly larger than the riskless rate. This rate is set by the monetary policy authority, and its level is assumed to be zero for simplicity.

The focus is on the idiosyncratic liquidity risk faced by individual banks, and on the interplay between this source of risk and the other fundamental banking risk, namely credit risk. I model each of them in turn below.

3.1.1 Liquidity risk and the interbank market

At $t = 0$, some banks are hit by a positive liquidity shock: they have a deposit inflow equal to x, so their retail deposits jump to $1 + x$ (where $0 < x < 1$). Other banks are hit by an opposite shock $-x$: their deposits decline to $1 - x$. Each of these liquidity shocks is either "permanent" or "transitory". A permanent shock lasts until $t = 2$. A transitory shock lasts only until $t = 1$: at this date the deposit level comes back to 1. A bank observes the nature of the shock at $t = 1$, while at $t = 0$ she knows that it is permanent with probability p. This framework is designed to formalize in a simple way the random nature of liquidity shocks: a shock today might be wiped out tomorrow by another one of the opposite sign. Moreover, liquidity shocks are assumed to be publicly observable; thus our results do not depend on any opportunistic behavior due to asymmetric information

by a bank. Therefore it seems reasonable to set the initial level of liquid reserves at an exogenous value (zero for simplicity), and to study banks' reactions to any deviations of available reserves from such a level.

[4] Fair pricing of the deposit insurance is a technical assumption, introduced in order to avoid any incentive distortion (risk-taking attitude) arising from flat insurance premia.

about individual liquidity imbalances[5]. Table 1 shows the impact of liquidity shocks on the deposits available to individual banks.

Table 1 - Liquidity shocks and bank deposits

$t = 0$	$t = 1$	
shock	*permanent*	*transitory*
$1 + x$	$1 + x$	1
$1 - x$	$1 - x$	1

In both periods $t = 0, 1$ banks *long* of liquidity can lend in the interbank market. In particular, in $t = 0$ both a short term (ST) and a long term (LT) interbank markets exist: a ST loan matures at $t = 1$ and a LT loan matures at $t = 2$. In $t = 1$ only a ST market is available by definition, as all loans have to be repaid by $t = 2$. As an alternative, banks can store liquidity in a riskless asset (e.g. Treasury Bills or reserves held at the central bank): this is safe and perfectly liquid, but its return is zero.

Banks *short* of liquidity can either borrow in the interbank market or liquidate loans. The latter alternative is costly, since loans are illiquid in nature (see the next subsection).[6]

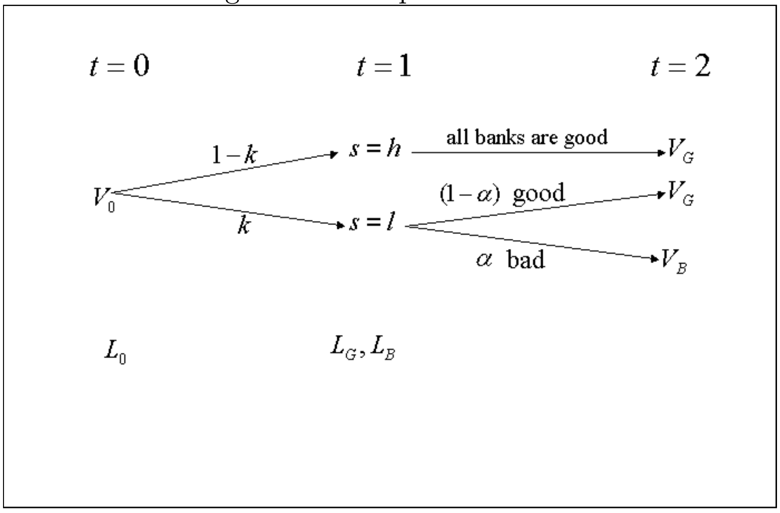
3.1.2 Credit risk

The are two states of nature, high and low: $s \in \{h, l\}$. If $s = h$ all banks are "good" (G): their loan portfolio is worth $V_G \geq 1 + x$, provided it is not liquidated until $t = 2$. To the contrary, if $s = l$ a share α of the banking system is made up of "bad" (B) banks: these have a loan portfolio which is worth $V_B \leq 1 - x$ in $t = 2$. In particular, V_G is assumed to be large enough that a good bank is always solvent at $t = 2$ (i.e. able to repay all her retail deposits plus interbank liabilities). To the contrary, V_B is assumed to be low enough that a bad bank is always insolvent at $t = 2$. Moreover, retail depositors (or equivalently the deposit insurer) have a senior claim, so an

[5] The alternative assumption that liquidity shocks are private information would strengthen the results below, since it would make a gridlock in the interbank market even more likely (see footnote 11).

[6] A further alternative that could be considered is borrowing from the central bank. However this generally occurs at a penalizing interest rate, and this penalty would play in my framework much the same role as the liquidation cost introduced below. Therefore I do not consider it explicitly here. The role of the discount window policy is discussed in Section 4.

Figure 1: Loan portfolio value



interbank debt maturing at $t = 2$ is never repaid by a bad bank[7]. Figure 1 shows the structure of the credit risk introduced here.

This framework formalizes the idea that with some probability (say k) a negative shock hits the market at $t = 1$, implying that some participants suffer losses large enough to become "lemons". An example is the bankruptcy of a large financial intermediary, having obligations with many other institutions in several countries: the distribution among market participants of the losses implied by this shock is difficult to asses in a short time. During the global financial crisis starting in August 2007, the concerns that some bad news of such a kind could be released grew substantially, relative to normal times (and some very bad news did eventually hit the market, like the Lehman Brothers' bankruptcy). The evidence reported in the Appendix documents that the probability of bank failures has shown a dramatic increase during the crisis.

In $t = 1$ everyone observes which state occurs, but each bank observes only her own type: the final value of the loan portfolio is a private information at this date. Of course, this private information problem is relevant

[7]This seniority assumption is introduced for simplicity: the recovery rate on an interbank loan to a bad bank is zero. Allowing for a positive recovery rate would not alter the results below.

only in the low state; in this case an interbank claim maturing at $t = 2$ will be repaid with probability $(1-\alpha)$,[8] as far as the lender knows.

As of $t = 0$ all banks are identical: each of them is aware that there can be a shock in the financial system at $t = 1$, making some banks $-$ possibly including herself $-$ to be lemons. Each bank's loan portfolio is worth $V_0 = \pi V_G + (1-\pi)V_B$, where $\pi = (1-k) + k(1-\alpha)$ and $V_0 > 1$ by assumption. A LT interbank claim will be repaid with probability π. To the contrary, a ST loan is riskless, since all banks are assumed to be always able to repay their interbank liabilities at $t = 1$, either by rolling over a ST debt or by liquidating part of their loan portfolio (formally: $L_B \geq x$)[9].

In case of early liquidation in $t = 1$, a bank's loan portfolio is worth L_G or L_B, depending on her type. If liquidated at $t = 0$, loans are worth L_0 for all banks. For simplicity, the ratio between the continuation and the liquidation value is assumed to be the same in all cases: $l = \frac{V_G}{L_G} = \frac{V_B}{L_B} = \frac{V_0}{L_0} > 1$.[10]

3.2 The liquidity management problem

The crucial decision a bank has to take at $t = 0$ is whether to trade in the interbank market and, if so, whether to trade ST or LT. Each of these acts has a quite different impact on the liquidity position of the bank in the next period, depending on whether a liquidity shock turns out to be either permanent or transitory. We have to analyze in some detail this issue before solving the model.

Consider first a bank hit by a *positive* liquidity shock: she is long of liquidity at $t = 0$. Suppose she lends ST (or stores) at this date:

- if the shock is *permanent*, at $t = 1$ she is still long of liquidity: she can lend again (or store);

- if the shock is *transitory*, her liquidity position is balanced at $t = 1$: the deposit outflow (from $1 + x$ to 1) is funded by the incoming repayment of the interbank loan (or by drawing on the liquid reserves previously stored).

Now suppose that she lends LT at $t = 0$:

- if the shock is *permanent*, her position is balanced at $t = 1$: there is no inflow/outflow of liquidity at this date;

[8] To be precise, this is the average repayment probability in the pooling equilibrium described below. As we shall see, an alternative scenario is one with no trade at $t = 1$.

[9] Note that the above assumption, that retail deposits are a senior claim, is actually enforced only at $t = 2$. Due to the passive behavior of retail depositors, interbank loans are *de facto* $-$ although not formally $-$ senior at $t = 1$.

[10] It must be stressed that this is only a simplifying assumption, not necessary to get the results below. To the contrary, Heider - Hoerova - Holthausen (2009) need to assume that the opportunity cost of liquidation is higher for a riskier bank.

- if the shock is *transitory*, she is going to be short of liquidity at $t = 1$: she will have to fund the deposit outflow (from $1+x$ to 1) either by borrowing in the interbank market or by liquidating part of her loan portfolio.

The same reasoning applies to a bank hit by a *negative* liquidity shock: she is short of liquidity at $t = 0$. Suppose she borrows ST at this date:

- if the shock is *permanent*, she is still short of liquidity at $t = 1$: she has to borrow again or to liquidate some loans;

- if the shock is *transitory*, her liquidity position is balanced at $t = 1$: she repays her interbank debt by the deposit inflow (from $1 - x$ to 1).

Suppose instead that she borrows LT (or liquidates) at $t = 0$:

- if the shock is *permanent*, her position is balanced at $t = 1$: there is no inflow/outflow of liquidity at this date;

- if the shock is *transitory*, she is going to be long of liquidity at $t = 1$: she will lend out (or store) the deposit inflow (from $1 - x$ to 1).

Table 2 summarizes the above discussion. It can be noted that if a bank trades ST at $t = 0$ and the liquidity shock is transitory, or alternatively if she trades LT and the shock is permanent, her liquidity position is balanced at $t = 1$: she does not need to take any action at this date. To the contrary, if a bank trades ST at $t = 0$ and the shock is permanent, she finds herself at $t = 1$ in the same situation as she was in the previous period; in particular, she has to roll over her debt in presence of a negative shock. More interestingly, if a bank trades LT at $t = 0$ and the shock turns out to be transitory, her liquidity position is reversed at $t = 1$ and she has to trade in a way opposite to what she did before. In particular, a bank hit by a positive liquidity shock and lending LT undertakes the risk of being short of liquidity in the next period; this risk is going to play a crucial role below in determining the liquidity premium.

Table 2 - The liquidity management problem

$t = 0$		$t = 1$	
SHOCK		PERMANENT	TRANSITORY
$1 + x$	lend ST (store)	long: lend (store)	balanced: do nothing
long	lend LT	balanced: do nothing	*short*: borrow (liquidate)
$1 - x$	borrow ST	*short*: borrow (liquidate)	balanced: do nothing
short	borrow LT (liquidate)	balanced: do nothing	long: lend (store)

In the following, we are going to solve the model backward. First, we determine the alternative equilibria prevailing in the interbank market at $t = 1$, depending on the state of nature governing the evolution of credit risk ($s \in [h, l]$) and on parameter values. Second, we determine the alternative equilibria at $t = 0$, which of course depend on the possible outcomes obtained at $t = 1$.

3.3 The interbank market at $t = 1$

We want to determine whether at $t = 1$ there are trades in the interbank market and, if so, at which rate of interest. If there is a positive volume of trades, the interbank market is said to be "*active*". The alternative situation, where no trade takes place, is labelled "*gridlock*". We know that at $t = 1$ only ST trades are possible by definition. We also know that there are some banks long of liquidity: they can either lend in the interbank market or store. Other banks are short of liquidity: they can either borrow or liquidate. These outside options allow us to identify their reservation prices for trading in the interbank market: the lowest interest rate asked by a lending bank and the highest rate that a borrowing bank is ready to pay.

An *interbank loan* at $t = 1$ is defined as a trade where a bank transfers at this date an amount x to another bank, and the latter promises to repay R at $t = 2$. I label $\underline{R}$ the lending bank's reservation price and $\overline{R}$ the borrower's reservation price. The feasibility condition for an interbank loan at $t = 1$ is: $\underline{R} \leq \overline{R}$.

Let us begin by examining the simple case where the good state occurs: $s = h$.

Proposition 1 *Let $s = h$ at $t = 1$. The interbank market is active and the equilibrium price is $\underline{R}_h = x$.*

Proof. *Interbank loans are riskless, so lenders' reservation price is $\underline{R}_h = x$. As an alternative to borrowing, a short bank has to liquidate a share $\frac{x}{L_G}$ of her loan portfolio, giving up a return $\frac{x}{L_G}V_G = xl$, with $l > 1$; so $\overline{R}_h = xl$. Hence $\overline{R}_h > \underline{R}_h$: the feasibility condition is met. Due to competition among lenders, the equilibrium price is $\underline{R}_h = x$. At this price all banks short of liquidity borrow, since liquidating is more costly.* ■

So in the good state trades take place at the riskless rate of interest, since all banks are able to repay for sure at $t = 2$. All banks short of liquidity are able to borrow in the interbank market.

The issue becomes more interesting in the low state: $s = l$.

Proposition 2 *Let $s = l$ at $t = 1$.*

(A) If $l \geq \frac{1}{(1-\alpha)}$, the interbank market is active and the pooling equilibrium price is $\underline{R}_l = \frac{x}{(1-\alpha)}$.

(B) If $l < \frac{1}{(1-\alpha)}$, there is a gridlock in the interbank market.

Proof. *(A) In a pooling equilibrium a lender in the interbank market is repaid with probability $(1-\alpha)$, so lenders' reservation price is given by $(1-\alpha)\underline{R}_l = x$. A good bank borrowing in the interbank market has a reservation price $\overline{R}_l = xl$. Hence $\overline{R}_l \geq \underline{R}_l$: the feasibility condition is met. A bad bank never repays an interbank debt, so the expected cost of borrowing in the interbank market is zero, while liquidating would cost $\frac{x}{L_B}V_B = xl$. Hence she is ready to (promise to) pay any price for borrowing and the feasibility condition is trivially met. Due to competition among lenders, the equilibrium price is $\underline{R}_l = \frac{x}{(1-\alpha)}$. At this price all banks short of liquidity borrow, since liquidating is more costly.*

(B) A good bank short of liquidity has a reservation price $xl < \frac{x}{(1-\alpha)}$. Hence the pooling price – obtained in (A) – is not an equilibrium price, since the feasibility condition fails to hold for good banks. Banks long of liquidity are aware that only bad banks are ready to borrow (at any price) in the interbank market, so they do not lend. ■

Proposition 2 shows that the emergence of a lemon problem in the interbank market ends up with two quite different outcomes, depending on the size of the liquidation cost relative to the share of "lemons" present in the banking system. For any value of α, if the liquidation cost is high enough, good banks short of liquidity prefer to borrow and the pooling equilibrium is feasible. In this case, the only consequence is a rise of the price charged on interbank loans, which has to incorporate a premium for the credit risk incurred by the lender. The (standard) implication is that – on the borrowing side – good banks subsidize bad ones[11]. If the liquidation cost is instead low enough, good banks are no longer ready to pay the bill and they prefer to liquidate. In this case, the pooling equilibrium breaks down and no bank is able to raise funds in the interbank market. As a consequence, all banks short of liquidity suffer a liquidation cost.

The crucial insight given by Proposition 2 is that, if the value of α during a financial crisis differs considerably from "normal times", this may have relevant consequences for the market equilibrium. A lemon problem might

[11] The assumption that liquidity shocks are public information rules out opportunistic behavior by bad banks, which are *not* short of liquidity, when the pooling equilibrium prevails. If these banks try to make a profit by borrowing and storing liquidity (exploiting the information that they will not repay the interbank debt), the other market participants are able to detect such banks and they do not lend to them. Allowing for such an opportunistic behavior – by assuming that liquidity shocks were privately observed – would increase the number of bad banks borrowing in the interbank market. As a consequence, lenders' reservation price would increase, making a gridlock even more likely to occur.

emerge also in normal times, but during a crisis period market participants fear that its impact is going to be stronger, for several reasons. For example, because they believe that a large intermediary may possibly fail, causing losses to many other institutions, while normally this is ruled out by the "bail out" policy of supervisory authorities. In 2008 there have been a growing concern that the authorities were not sticking to the "too-big-too-fail" doctrine, and the Lehman Brothers bankruptcy confirmed that such concern was well grounded. So the distinctive feature of a crisis period is the possibility of a large shock hitting the market, with a negative impact on so many participants to lead to a gridlock (formally, a crisis period features a higher value of α relative to normal times).

3.4 The interbank market at $t = 0$

At $t = 0$ both a ST and a LT interbank markets exist. We want to identify the conditions under which these markets are active and, in such a case, the equilibrium prices.

A *ST interbank loan* at $t = 0$ is defined as a trade where a bank transfers at this date an amount x to another bank, and the latter promises to repay R_1 at $t = 1$. Similarly, a *LT interbank loan* at $t = 0$ is defined as a trade where a bank transfers at this date an amount x to another bank, and the latter promises to repay R_2 at $t = 2$. As we know, the outside option to trading in the interbank market is to store liquidity for a long bank, and to liquidate a share of her loan portfolio for a short bank. These outside options determine their reservation prices: $\underline{R}_1, \underline{R}_2$ and $\overline{R}_1, \overline{R}_2$ for a long and for a short bank respectively. The feasibility condition must now be met in both the ST and the LT markets: $\underline{R}_1 \leq \overline{R}_1$ and $\underline{R}_2 \leq \overline{R}_2$ respectively.

Moreover, for both markets to be active all banks must be indifferent between trading in the ST and in the LT markets. The comparison between the payoffs obtained by trading ST and LT has to take into account not only the equilibrium prices, but also the implications that trading at $t = 0$ bears on the liquidity position of a bank in the next period, and on her need to trade again at $t = 1$ (as illustrated in Table 2).

The equilibrium at $t = 0$ crucially depends on the outcome obtained at $t = 1$. As we have seen in the previous section, a gridlock in the interbank market can occur at $t = 1$ when the following condition fails to hold:

$$l \geq \frac{1}{(1-\alpha)} \tag{1}$$

Therefore I consider two separate cases: (A) condition (1) holds; (B) condition (1) does not hold.

3.4.1 Case (A): no gridlock at $t = 1$

Proposition 3 *Let $l \geq \frac{1}{(1-\alpha)}$. Both the ST and the LT interbank markets are active at $t = 0$. The equilibrium prices are $\underline{R}_1 = x$ and $\underline{R}_2 = \frac{x}{\pi}$ respectively.*

Proof. ST market. *ST interbank loans are riskless, so lenders' reservation price is $\underline{R}_1 = x$. As an alternative to borrowing, a short bank has to liquidate a share $\frac{x}{L_0}$ of her loan portfolio, giving up a return $\frac{x}{L_0}V_0 = xl$, with $l > 1$; so $\overline{R}_1 = xl$. Hence $\overline{R}_1 > \underline{R}_1$: the feasibility condition is met. Due to competition among lenders, the equilibrium price is $\underline{R}_1 = x$.*

LT market. *LT interbank loans are repaid with probability π, so lenders' reservation price is given by $\pi\underline{R}_2 = x$ and borrowers' reservation price is given by $\pi\overline{R}_2 = xl$. Hence $\overline{R}_2 > \underline{R}_2$: the feasibility condition is met. Due to competition among lenders, the equilibrium price is $\underline{R}_2 = \frac{x}{\pi}$.*

At the equilibrium prices $\underline{R}_1$ and $\underline{R}_2$, banks short of liquidity borrow, since liquidating is more costly.

All banks are indifferent between trading ST and LT, since the expectation – as of $t = 0$ – of their final value is as follows[12]. *The expected value of a long bank lending ST is*[13]*:*

$$p\left[V_0 + (1-k)\underline{R}_h + k(1-\alpha)\underline{R}_l - (1+x)\right] + (1-p)\left(V_0 - 1\right) = V_0 - 1 \quad (2)$$

The expected value of a long bank lending LT is[14]*:*

$$p\left[V_0 + \pi\underline{R}_2 - (1+x)\right] + (1-p)\left\{V_0 + \pi\underline{R}_2 - \left[(1-k)\underline{R}_h + k(1-\alpha)\underline{R}_l\right] - 1\right\} = V_0 - 1 \quad (3)$$

[12] The expectations below are computed by taking the difference between the values of assets and liabilities, including the positions to be taken at $t = 1$ in the interbank market, if any. Contrary to interbank debt, retail deposits appear in the expressions below with a repayment probability equal to one: this is due to the assumed fair pricing of the deposit insurance scheme, through which any expected liability of the deposit insurer is internalized to the bank issuing deposits.

[13] This value is calculated by assuming that the bank rolls over the loan at $t = 1$, if the liquidity shock is permanent. The same result is obtained if the bank stores the excess liquidity at $t = 1$ (this could happen because of the aggregate excess liquidity assumed in our set-up).

[14] Note that if the liquidity shock is transitory the bank has to borrow at $t = 1$. The probability of repaying this debt in the low state ($s = l$) is $(1 - \alpha)$, with the information available at $t = 0$.

The expected value of a short bank borrowing ST is:

$$p\left\{V_0 - [(1-k)\underline{R}_h + k(1-\alpha)\underline{R}_l] - (1-x)\right\} + (1-p)(V_0 - 1) = V_0 - 1 \quad (4)$$

The expected value of a short bank borrowing LT is:

$$p\left[V_0 - \pi\underline{R}_2 - (1-x)\right] + (1-p)\left\{V_0 - \pi\underline{R}_2 + [(1-k)\underline{R}_h + k(1-\alpha)\underline{R}_l] - 1\right\} = V_0 - 1 \quad (5)$$

■

Proposition 3 shows that, given that the interbank market is active at $t = 1$, the spread between the LT and the ST interbank rates at $t = 0$ incorporates only a credit risk premium, due to the possibility that a LT loan will not be repaid, whereas a ST loan is risk-free. Thus the spread is:

$$\underline{R}_2 - \underline{R}_1 = x\left(\frac{1}{\pi} - 1\right) \quad (6)$$

The liquidity risk, namely the risk of being short of liquidity in the next period, plays no role in this context, since a bank is always able to raise funds in the interbank market at an interest rate reflecting her credit risk, thus paying an expected rate of interest equal to zero. Under this regard, the possibility that the ST interest rate jumps from the riskless level to a positive one, due to an increase of credit risk, bears no consequence. Both the ST and the LT markets are active, since the expected value of a bank − as of $t = 0$ − does not depend on the maturity of her interbank trade, so she is indifferent between trading ST and LT.[15] This expected value is $V_0 - 1$ regardless of the sign of the liquidity shock, thanks to the redistribution of liquidity taking place through the interbank market. Things are going to change in case (B).

3.4.2 Case (B): possible gridlock at $t = 1$

Proposition 4 *Let $l < \frac{1}{(1-\alpha)}$. If $p < (>)\frac{1}{2}$, only the ST (LT) interbank market is active at $t = 0$. If $p = \frac{1}{2}$, both the ST and the LT markets are active. The equilibrium prices are $\underline{R}_1 = x$ and $\underline{R}_2 = \frac{x}{\pi}[1 + (1-p)k(l-1)]$ respectively.*

Proof. ST market*. The same as in Case (A).*

LT market*. LT interbank loans are repaid with probability π. Lenders' reservation price is given by $\pi\underline{R}_2 - x(1-p)k(l-1) = x$: the expected cost of*

[15] This result contrasts the one obtained in Eisenschmidt - Tapking (2009), where a possible future rise of interest rates − reflecting a positive default probability − is enough to make the long term interbank market break down.

funding a LT loan by liquidating at $t = 1$ must be subtracted from the expected return on such a loan. Borrowers' reservation price is given by $\pi\overline{R}_2 = xl$. It is easy to check that $\overline{R}_2 > \underline{R}_2$: the feasibility condition is met. Due to competition among lenders, the equilibrium price is $\underline{R}_2 = \frac{x}{\pi}[1 + (1-p)k(l-1)]$.

Banks long of liquidity are indifferent between lending ST and LT, since the expectation – as of $t = 0$ – of their final value is as follows. The expected value if lending ST is[16]*:*

$$p[V_0 + x - (1+x)] + (1-p)(V_0 - 1) = V_0 - 1 \tag{7}$$

The expected value if lending LT is[17]*:*

$$p[V_0 + \pi\underline{R}_2 - (1+x)] + (1-p)\{V_0 + \pi\underline{R}_2 - [(1-k)\underline{R}_h + kxl] - 1\} = V_0 - 1 \tag{8}$$

At the equilibrium prices $\underline{R}_1$ and $\underline{R}_2$, banks short of liquidity borrow, since liquidating is more costly. They prefer to borrow either ST if $p < \frac{1}{2}$, or LT if $p > \frac{1}{2}$ (they are indifferent if $p = \frac{1}{2}$), since the expectation – as of $t = 0$ – of their final value is as follows. The expected value if borrowing ST is:

$$p\{V_0 - [(1-k)\underline{R}_h + kxl] - (1-x)\} + (1-p)(V_0 - 1) = V_0 - 1 - pkx(l-1) \tag{9}$$

The expected value if borrowing LT is:

$$p[V_0 - \pi\underline{R}_2 - (1-x)] + (1-p)[V_0 - \pi\underline{R}_2 + x - 1] = V_0 - 1 - (1-p)kx(l-1) \tag{10}$$

■

Proposition 4 highlights the main points of this paper. First, the spread between the LT and the ST interbank rates at $t = 0$ incorporates not only a credit risk premium, but also a liquidity risk premium. Thus the spread is now:

$$\underline{R}_2 - \underline{R}_1 = x\left[(\frac{1}{\pi} - 1) + \frac{(1-p)k(l-1)}{\pi}\right] \tag{11}$$

The second term in brackets is the compensation asked by a bank lending LT for the risk she incurs of being short of liquidity in the next period and

[16] If the liquidity shock is permanent, the bank either lends x at $t = 1$ (in state $s = h$) or stores (in state $s = l$). In both cases the value of this excess liquidity is x.

[17] Note that if the liquidity shock is transitory and the state is $s = l$, the bank has to liquidate at $t = 1$, giving up xl.

being forced to liquidate part of her loan portfolio: this happens if the initial positive liquidity shock is eventually reversed and there is a gridlock in the interbank market at $t = 1$. Note that the liquidity premium is due to the interplay between the credit risk and the liquidity risk: both elements are necessary to generate a positive liquidity premium (it is immediate to see that the liquidity premium vanishes if either $k = 0$ or $p = 1$). The model is then able to explain the dramatic increase of the spread between medium term and short term interest rates (say three month − overnight) taking place during the liquidity crunch of 2007-2008: the risk of a gridlock of the interbank market in the near future seems to play a relevant role, since it introduces an additional component into such a spread.

Second, banks initially short of liquidity are not indifferent (in general) between borrowing ST and LT. They have to compare the liquidity premium charged on a LT loan with the liquidity risk they incur by borrowing ST: a ST debt should be rolled-over in the next period if the liquidity shock is permanent, but this is not possible if the interbank market is gridlocked at $t = 1$, implying a liquidation cost. The balance between these two costs depends on p. If the liquidity shock is more likely to be permanent ($p > \frac{1}{2}$), the liquidity premium charged on a LT loan is more than outweighed by the risk of being forced to liquidate at $t = 1$: than all banks short of liquidity at $t = 0$ prefer to pay the price of borrowing LT. The opposite happens if the liquidity shock is more likely to be transitory ($p < \frac{1}{2}$): in this case the liquidity premium on a LT loan is too high and all short banks prefer to borrow ST[18]. Therefore trades drop to zero either in the ST or in the LT interbank market. The latter case seems to be more relevant in the interpretation of the liquidity crunch: the available evidence points to a "flight to overnight" in the trading activity. The model is able to explain this polarization of trades: this is presumably due to a high volatility of the liquidity shocks during the financial turmoil, inducing the lending banks to ask a high liquidity premium and the borrowing banks to react by trading on very short maturities (some evidence supporting this view is provided in the Appendix).

Again, it must be stressed that such a polarization of trades occurs only in presence of a risk of gridlock of the interbank market in the near future (case B in our model). To the contrary, the risk of an increase of the interbank interest rate, due to a possible future shock to credit risk (case A),

[18] Note that this happens despite the fact that the equilibrium liquidity premium is the minimum needed for a lending bank to break-even (i.e. to get an expected return equal to zero), thanks to the assumption of competition among lenders.

is not able to produce the same outcome. It is also worth noting that multiple equilibria and coordination failures are not at work here: given the values of model parameters, a unique equilibrium is determined. As mentioned before, the equilibrium described in case A seems to be appropriate in normal times, while case B becomes relevant under a crisis scenario.

Finally, note that an inefficient liquidation of illiquid loans is unavoidable in the low state (case B), and the expected cost of this inefficiency is paid by those banks initially hit by a negative liquidity shock. They pay directly the liquidation cost if they borrow ST at $t = 0$ and they are eventually forced to liquidate at $t = 1$. Alternatively, banks lending LT may be forced to liquidate at $t = 1$, but they are able to translate the expected liquidation cost to the borrowing banks at $t = 0$.

4 Policy implications

A key element of the model is the adverse selection issue raised by the lack of information about the quality of bank assets. The first policy implication is that the intervention of the authorities should be devoted to improving the transparency of financial institutions and markets. The complexity of large (international) financial groups have worsened the quality of the information released through their balance sheets. The opacity of the OTC markets has prevented market participants from having a clear picture of the distribution of losses arising from the crisis of specific market segments (like ABS). A regulatory and supervisory intervention in this area is needed[19].

To the contrary, the management of aggregate liquidity − through central bank open market operations − does not seem to be the right answer to the issues raised here, since none of the above results derives from an aggregate shortage of liquidity. Of course, aggregate liquidity shocks do take place in the real world, calling for central bank intervention. However, increasing the supply of bank reserves seems unable to solve issues which are ultimately related to the creditworthiness of counterparties.

Actually, central banks' intervention could still be effective within the context of the model, but only by putting taxpayers' money at risk. If, in case of a gridlock at $t = 1$, the central bank stands ready to lend to all banks short of liquidity, such banks would borrow x from the central bank instead

[19] The Financial Stability Forum has stressed the role of transparency: financial institutions should release reliable information on their risk exposures (including off-balance sheet items and securitized products) to restore market confidence. Regulators and supervisors are invited to act in order to achieve that goal. See FSF (2008).

of liquidating, provided the amount to be repaid to the central bank does not exceed xl (the reservation price of good banks). This kind of intervention would avoid an inefficient liquidation of bank assets. If anticipated, it would also avoid banks long of liquidity asking for a liquidity premium on LT interbank loans. However, the provision of this discount window facility would imply an expected loss for the central bank (equal to $x-(1-\alpha)xl$, if the highest feasible rate is applied). The moral hazard implications of this action should also be carefully considered.

This line of intervention has indeed been adopted by some central banks, after observing the inefficacy of traditional open market operations. For example, the ECB was unable to restore normal conditions in the euro area money market by allotting liquidity through auctions with a predetermined limited amount, despite all the efforts made to accommodate the aggregate demand for liquidity of the banking system[20]. Banks were aware that the liquidity injected was not properly redistributed through the interbank market, and that borrowing from the central bank might imply paying a penalizing rate: either by submitting aggressive bids in monetary policy auctions (see Figure 3 below), or by using the marginal lending facility. As a consequence, in October 2008 the ECB started to provide illimited amounts of liquidity at fixed interest rate in the main refinancing operations; at the same time, the range of eligible collateral has been enlarged and the penalization applied on the marginal lending facility has been halved (from 100 to 50 basis points). Moreover, the interest rate applied in monetary policy operations has been dramatically lowered (from 4.25% to 1% in several steps). The aim of these actions has been to assure banks that they would be able to get all the needed liquidity directly from the central bank without any penalization[21]. The ECB has been implicitly subsidizing the banking system, by providing unlimited liquidity at very low cost and by accepting low quality collateral[22]. At last, these extreme measures have been able to eliminate the

[20] See ECB (2008) for details on the Eurosystem's liquidity management in the early stages of the financial turmoil.

[21] Similar actions have been taken by the Fed: (i) the penalty on the primary discount lending has been lowered from 100 to 50 and then to 25 b.p. above the federal funds target rate, which in turn has been substantially lowered in several steps; (ii) reserves have been directly supplied to all U.S. banks through the Term Auction Facility (while only 19 primary dealers can participate in traditional open market operations); (iii) the range of collateral has been broadened through the Term Securities Lending Facility; (iv) primary dealers have been given access to discount window through the Primary Dealer Credit Facility. See Cecchetti (2009) for further details.

[22] The credit risk incurred by the Eurosystem in providing liquidity became evident when - in autumn 2008 - five counterparties defaulted on refinancing operations for a

abnormal liquidity premium charged on interbank loans beyond the shortest maturities (see Figure 4 below).

Finally, an insight of the model is that, due to a "lemon problem", solvent banks might not be able to raise liquidity in the money market in presence of a gridlock; alternatively they have to pay a credit risk premium. These outcomes could be avoided if the central bank were endowed with superior information on the creditworthiness of banks, thanks to its supervisory role. In such a case, the central bank would be able to lend money only to good but illiquid banks, in the spirit of the Bagehot's doctrine of the LOLR − as advocated by Rochet - Vives (2004). Unfortunately this does not seem to be a realistic scenario, at least by looking at the experience of the recent financial turmoil: apparently even the supervisory authorities did not have an accurate information about the quality of bank assets.

5 Concluding remarks

The lesson we can draw from the above analysis is that the chance of a bad news hitting the market in the future bears important consequences for the equilibrium prevailing in the interbank market. If market participants believe that such a bad news can lead to a gridlock, they demand a liquidity premium for lending at maturities longer than very short ones. They fear that an excess of reserves turns later into a shortage: if this should happen, they would come back to the market and find that it is not there any more, forcing them to liquidate some illiquid assets. The liquidity premium can get so high that banks short of liquidity prefer to borrow short term, originating a "flight to overnight" (despite the fact that by doing so they incur in a roll-over risk). These findings rely on the possibility that a negative shock brings an adverse selection problem into the picture, which can be traced back to credit risk together with hidden information about the distribution of losses among market participants. Thus the interplay between credit and liquidity risks plays a crucial role.

All the ingredients, necessary to obtain the above outcomes, have been present in the global financial turmoil of 2007-2009. (i) Some bad news hitting the market have generated concerns that other − even worse − news might eventually be released. (ii) The lack of information about the (cross-

total amount of euro 10.3 billions. The ECB acknowledged that the ABSs submitted as collateral were not liquid. As a consequence, the Governing Council decided that the NCBs should establish a total provision of 5.7 billions in their annual accounts for 2008. See ECB (2009, b).

border) exposure of market participants to troubled institutions or "toxic" assets has created a classic "lemon problem". (iii) Banks have become more uncertain about their liquidity needs, due to a higher volatility of liquidity shocks, thus bearing a higher funding risk.

The policy implication of this analysis is twofold. First, more transparency is needed to enable market participants to have a more accurate picture of the distribution of losses following a negative shock. Second, the supply of aggregate liquidity through open market operations may become ineffective under a liquidity crunch; this explains why some central banks have introduced some relevant innovations into their operational framework, which have implied a subsidy to the banking system.

Appendix – Default risk and liquidity crunch: some stylized facts

This Appendix documents some stylized facts taking place during the 2007 - 2009 financial crisis. It is not intended to provide a formal empirical test of the model presented above. Rather, it provides some evidence supporting both some crucial assumptions of the model and its main predictions. In summary, it shows the following facts: (i) the increasing risk of bank failure, measured by CDS premia; (ii) the more aggressive behavior of banks participating in monetary policy operations, which is an evidence of the increased liquidity (funding) risk; (iii) the jump of the liquidity premium charged on interbank deals beyond the shortest maturities; (iv) the decline of the trading activity in the interbank market; (v) the "flight to overnight" taking place right after the Lehman Brothers crash.

Figure 2 reports a plot of the premia paid on credit default swaps for the US and EU banks (the vertical lines mark two crucial dates: August 9th 2007 (start of the crisis) and September 15th 2008 (bankruptcy of Lehman Brothers)). It is apparent that, since the beginning of the crisis, the price of insuring against the risk of a bank default has dramatically risen. It is also evident that the collapse of Lehman Brothers was a crucial event, making CDS premia to reach unprecedented levels. Note that CDS premia in the U.S. have been rising sharply during the few months *preceding* the LB collapse: the market seems to be anticipating that some important institutions might suffer severe problems. Right after the LB collapse, CDS premia has been rising further, driven by the fear that other intermediaries might experience similar problems. During the spring of 2009, the new spike of CDS premia presumably reflects a growing concern that the recession, affecting the real sector of the economy, might produce further losses to the banking sector. This evidence is broadly consistent with the assumption, made in the

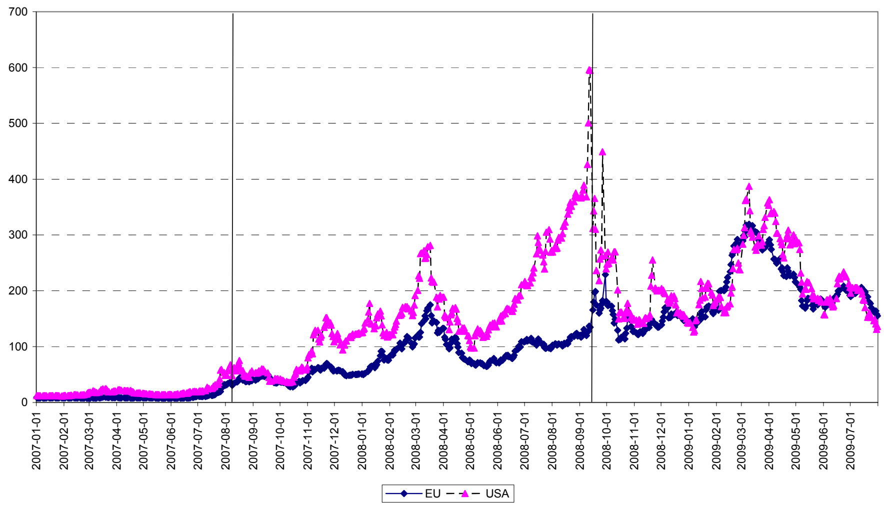


Figure 2: Banks CDS premia (Datastream 5Y Index - daily data - b.p.)

model set-up, that participants in the money market have anticipated the chance that a bad news might eventually hit the market, creating a lemon problem.

Another key element of the model is the volatility of liquidity shocks, which is captured by the parameter p: the lower is this, the higher is the chance that a current shock will be reversed in the next period. The uncertainty generated by random liquidity shocks is at the origin of the liquidity (funding) risk incurred by a bank, namely the risk of bearing large costs to find the liquidity needed to meet her obligations, possibly being forced to liquidate illiquid assets. Since it is not possible to directly observe the volatility of liquidity shocks for individual banks, a useful indicator of the liquidity risk is the behavior of banks participating in monetary policy operations[23]: banks facing a higher uncertainty relative to their future liquidity needs bid more aggressively in open market operations, given that some frictions prevent the interbank market from perfectly and costlessly redistributing the aggregate available liquidity. Figure 3 reports some information for the euro area: (i) the difference between the weighted average rate and the minimum bid rate in the main refinancing operations conducted by the ECB; (ii) the "cover ratio" in the same operations, defined as the ratio between total bids

[23] See Drehmann - Nikolaou (2009) and the literature referred to in their paper.

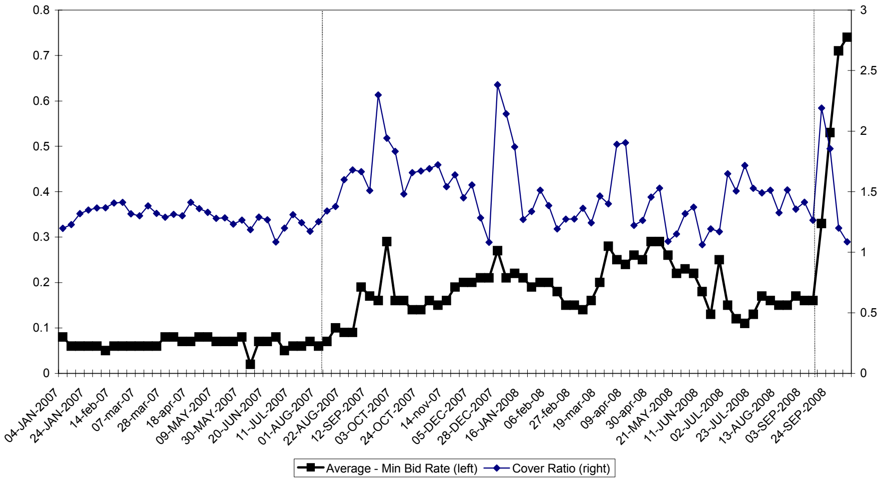


Figure 3: ECB main financing operations

and allotted amount. Both indicators document a more aggressive behavior of European banks since August 2007; moreover, the spread between average and minimum bid rate shows a jump after the LB collapse. This evidence points to an increase of funding risk. This in turn is due to both a higher volatility of liquidity shocks and higher frictions in the interbank market.

The sharp increase of frictions in the money market during the "liquidity crunch" is well known. However, most of the available evidence is focussed on interest rates, particularly on the evolution of the spread between rates at different maturities[24]. A picture like the one shown in Figure 4 has become a sort of "standard view" of the liquidity crisis. The jump of the spread to unprecedented levels has been stressed both by academic scholars and by practitioners.

To the contrary, the evidence relative to the volume of activity is much more scarce, due to the lack of data, which in turn is due to the OTC nature

[24] The spread between the 3 month interbank rate and the expected O/N rate over the same period (proxied by the O/N swap) is a benchmark widely used; this is reported in Figure 4 for the euro area. A similar information is given by other indicators, like: the spread between unsecured and secured interbank rates; the spread between the interbank rate and the rate on Government bills. References to the relevant literature are given in the Introduction.

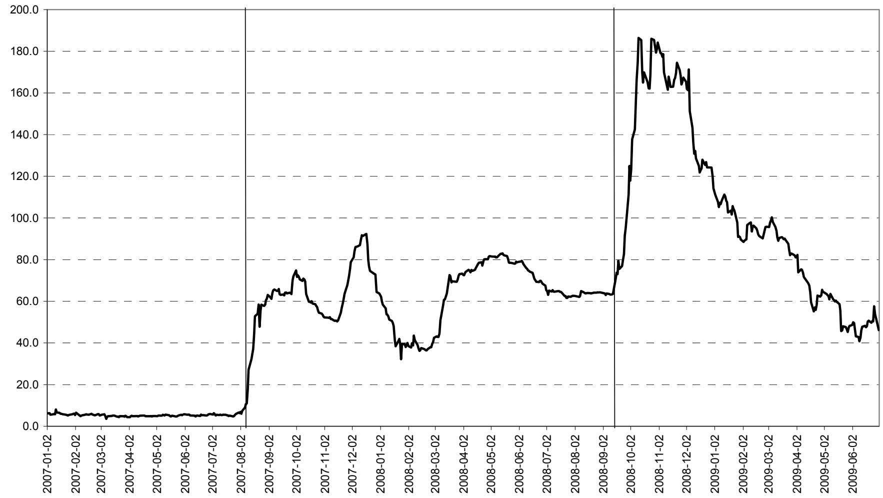


Figure 4: Spread 3 Month Euribor - Eonia Swap (daily data - b.p.)

of the money market. Therefore, I provide here some descriptive evidence on the trading activity in the e-MID market: this is an electronic platform where (unsecured) interbank loans are traded; it is located in Italy but most of their participants are from other countries of the euro area, so it is quite representative of the interbank market in this area[25]. My data set includes tick-by-tick data for trades on all maturities − from O/N to one year − taking place in e-MID for the period January 2007 - April 2009.

Figure 5 shows the pattern of the trading activity over the whole period. The solid line shows the daily number of trades (on all maturities), averaged over each month. The dashed line shows the average daily volume in each month. Both measures of trading activity exhibit a declining pattern. The daily number of trades, which used to be in a range between 400 and 450 in the first half of 2007, dropped to a 250-300 range a couple of years later. Over the same time span, the decline of traded volumes is even stronger: from a range between 25 and 30 billions to a 5-10 billion range. Thus, the liquidity crunch shows up not only in the number of deals, but also in their mean value, which has considerably declined (from 70.7 millions in 2007.01 to 26.7 in 2009.04)[26].

[25] After the introduction of the single currency, the money markets of the countries belonging to the euro area have rapidly become highly integrated; so they can be considered as a single market, and e-MID is a relevant part of it.

[26] ECB (2009, a) also finds a decline of the mean value of deals in e-MID between early

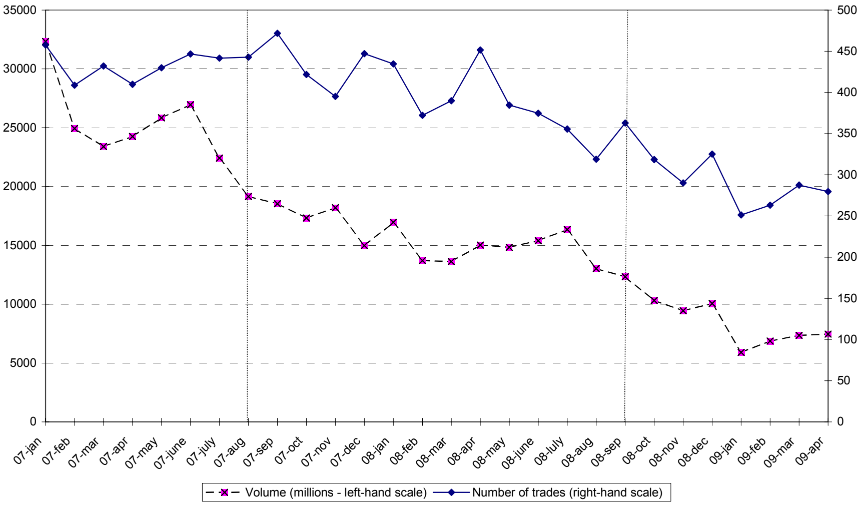


Figure 5: Daily activity in the e-MID market (monthly average)

The bulk of the trading activity in e-MID is concentrated on the overnight maturity: this accounts for more than 90% of the market (in terms both of volume and turnover). This share is quite stable and its evolution over the whole sample period does not show any interesting pattern. Therefore, in order to detect the so-called "flight to overnight", I provide an analysis of a specific episode − namely the collapse of Lehman Brothers − with high frequency data.

Figures 6 and 7 report the number of trades in each business hour, averaged over the week right before/after the announcement of the LB crash (8-12 Sept. / 15-19 Sept. 2008). While Figure 7 refers to overnight deals, Figure 6 refers to deals with longer maturities[27]. It can be seen that the two business hours where the market is more active are those between 9 a.m. and 11 a.m.. In this crucial time band, the number of trades with maturities longer than O/N dropped from about 7-8 per hour to 2 in the days following the LB crash: thus this market segment, which already played a

2007 and mid-2008, which is attributed to a lower share of large deals (those above 100 millions euro) over total.

[27] To be more specific, Figure 7 refers to O/N, T/N and S/N contracts, while Figure 6 refers to all the other contracts, with maturities from one week to one year. Only the number of trades are plotted in these two graphs. The traded volumes are highly volatile on an hourly basis, due to the random presence of some very large deals: this is the reason why they are not shown in these graphs.

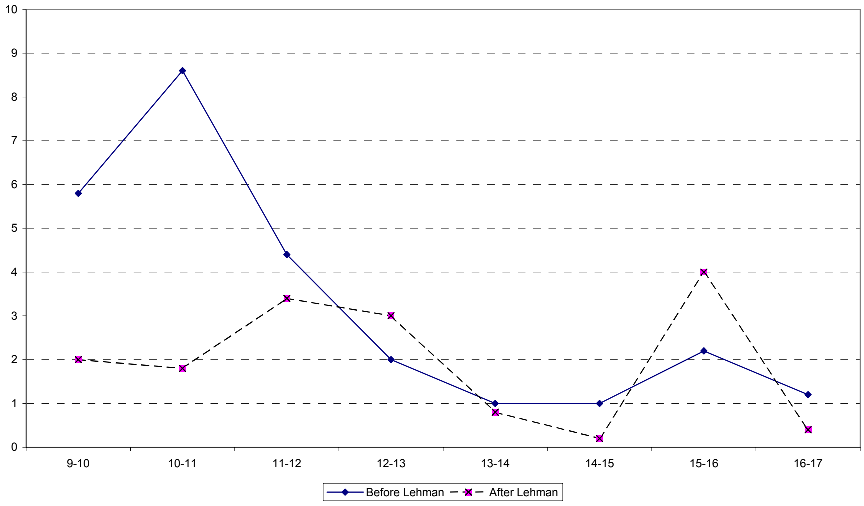


Figure 6: Number of trades in e-MID: maturities different from O/N (hourly average)

minor role, almost disappeared. To the contrary, the number of O/N deals was (weakly) larger at all times of the day after the LB crash. By looking at the daily number of trades we obtain the same outcome: the mean daily number of O/N trades increases from 320 in the week before the LB crash to 360 in the week after that event; at the same time the daily number of trades on longer maturities declines from 26 to 16. As a consequence, the share of O/N deals over total increases from 92% to 96%.[28]

These findings – although limited to a specific episode – provide some support to the "flight to overnight" effect, often referred to in the literature on the liquidity crunch. They show that, following the LB collapse, there was a migration of the trading activity from longer maturities to the O/N segment – despite the major role already played in e-MID by this segment even before the start of the crisis.

To conclude, the information provided in this Appendix documents – among other things – two stylized facts, which are consistent with the main

[28] These findings have been checked over a longer time span: two weeks before and after the LB crash. The result is confirmed: the daily number of O/N trades increases from 310 to 373, while the daily number of trades on longer maturities declines from 24 to 16; thus the share of O/N deals over total increases from 93% to 96%.

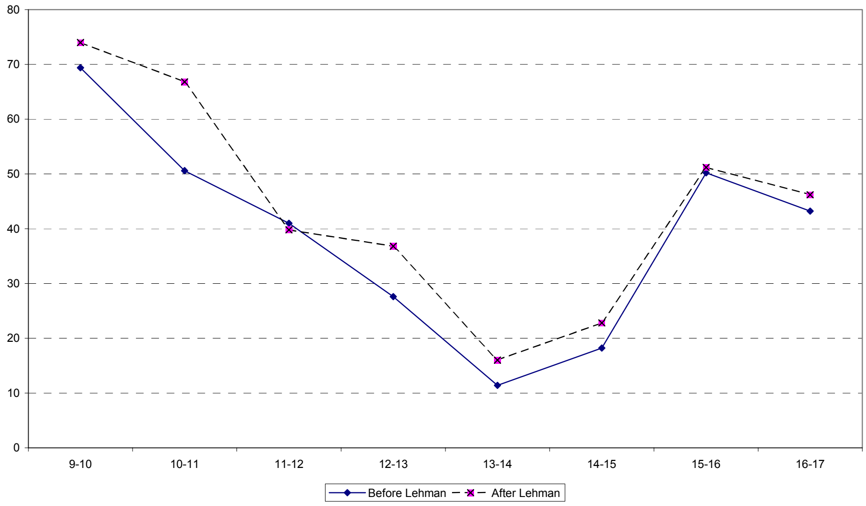


Figure 7: Number of O/N trades in e-MID (hourly average)

theoretical results of this article (stated in Proposition 4): (i) the jump of the spread between interest rates at different maturities, incorporating a high liquidity premium; (ii) the polarization of trades towards short maturities.

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