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Financial Amplification Mechanisms and the Federal Reserve's Supply of Liquidity during the Crisis

Asani Sarkar
Jeffrey Shrader

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Abstract

The small decline in the value of mortgage-related assets relative to the large total losses associated with the financial crisis suggests the presence of financial amplification mechanisms, which allow relatively small shocks to propagate through the financial system. We review the literature on financial amplification mechanisms and discuss the Federal Reserve's interventions during different stages of the crisis in terms of this literature. We interpret the Fed's early-stage liquidity programs as working to dampen balance sheet amplifications arising from the positive feedback between financial and asset prices. By comparison, the Fed's later-stage crisis programs take into account adverse-selection amplifications that operate via increases in credit risk and the externality imposed by risky borrowers on safe ones. Finally, we provide new empirical evidence that increases in the amount outstanding of funds supplied by the Fed reduce the Libor-OIS spread during periods of high liquidity risk. In contrast, reductions in the Fed's liquidity supply in 2009 did not increase the spread. Our analysis has implications for the impact on asset prices of a potential withdrawal of liquidity supply by the Fed.

Key words: financial amplification mechanism, Federal Reserve liquidity facilities; credit risk; liquidity risk; Libor-OIS spread

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Sarkar and Shrader: Federal Reserve Bank of New York. Corresponding author e-mail: asani.sarkar@ny.frb.org. The authors thank Viral Acharya, Mark Flannery, Gary Gorton, Arvind Krishnamurthy, and Lasse Pedersen for comments.

Introduction

One of the primary questions related to the recent financial crisis is how losses on subprime mortgage assets of roughly $300 billion[1] led to rapid and deep drops in both the value of a wide range of other financial assets and, increasingly, real economic output. The disproportionate size of total losses compared to the relatively small size of the initial trigger points to the presence of amplification mechanisms that allowed losses centered in one market to cause a system-wide downturn. A further question is why subprime mortgage backed securities (MBS) in particular, rather than any other asset, led to the downturn. Blanchard (2009) identifies the interaction between general market conditions, such as high leverage, under-pricing of risk, and high interconnectedness, with particular features of subprime MBS, such as opacity and a belief in ever rising housing prices, as key factors leading to the crisis. [2]

In this paper, we examine how these conditions identified by Blanchard and others led to widespread losses in financial markets by focusing on two financial amplification mechanisms of relevance to the crisis. We also interpret the actions of the Federal Reserve (the "Fed") in the context of these mechanisms, and we provide new empirical evidence on the effectiveness of the Fed's liquidity supply during the crisis.

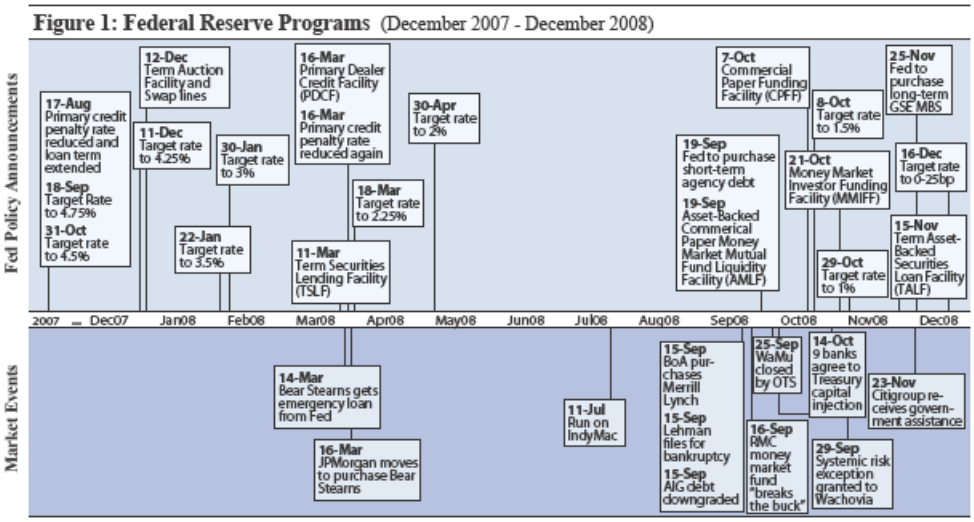
As the discussion above indicates, by a "financial amplification mechanism," we mean the process whereby an initial shock occurring within the financial sector triggers substantially larger shocks in the financial sector and the real economy. While a number of such mechanisms have

[1] See "Global Financial Stability Report, April 2008" the International Monetary Fund.
[2] Acharya and Richardson (2009), Adrian and Shin (2009), Brunnermeier (2009), Gorton (2008) and Blanchard (2009), among others, describe the genesis of the crisis and provide explanations for how it was propagated.

been proposed in the literature, we focus on two: balance sheet and adverse selection amplifiers. [3]

The balance sheet mechanism is often cited as an explanation for liquidity crises. For example, it has been used to explain the stock market crash of 1987 (Brunnermeier and Pedersen (2009)), the LTCM crisis of 1998 (Gromb and Vayanos (2002)) and the current crisis (Bernanke (2009)). The Bank of England (BOE) incorporates this mechanism into their quantitative Risk Assessment Model for Systemic Institutions RAMSI (Aikman et al (2009)). In all of these cases, the initial trigger was relatively small in magnitude and local (e.g. the Russian default in 1998 and mergers and acquisitions related news in 1987) but spread rapidly and broadly to other markets globally. The amplification underlying these events is suggested to operate as follows: an initial shock tightens funding constraints, causing net worth of institutions to decrease, and funding conditions to tighten further. We discuss the different ways proposed in the literature for funding shocks to lower net worth (e.g. higher margins, lower value of collateral, lower asset market prices and higher volatility). Since the literature is extensive, we focus on a small number of key contributions that introduce alternative feedback loops between funding shocks and changes in net worth (or, more generally, balance sheet conditions).

[3] Other examples of amplification mechanisms are the maturity mismatch between assets and liabilities (Diamond and Dybvig (1983)), Knightian uncertainty (Krishnamurthy (2009) and Pritsker (2009)) and interdependency from credit chains where firms are simultaneously borrowing and lending (Kiyotaki and Moore (1997b)).



Central Banks appear well-placed to mitigate funding constraints as the Lender of Last Resort (LOLR). Since banks typically fund long-term assets with short-term money, a loss of confidence would force them to engage in fire-sale of assets. By providing a liquidity backstop, this potential fire-sale is avoided. Bernanke (2009) describes the stages of the Federal Reserve's responses in the current crisis. The first stage programs—the Term Auction Facility (TAF), central bank liquidity swaps, Term Securities Lending Facility (TSLF), Primary Dealer Credit Facility (PDCF)—introduced between December 2007 and March 2008 (see Figure 1), involved the provision of short-term liquidity to sound financial institutions, in line with the Fed's traditional role of LOLR. [4]

We describe the Fed's first stage liquidity programs and discuss available evidence regarding the effectiveness of these programs. The evidence is consistent with the view that the Fed mitigated funding stresses by charging lower effective rates on collateralized funds

[4] We do not consider the Fed's term financing to JPMorgan Chase for the acquisition of Bear Stearns on March 14, 2008 as a liquidity program but rather as a one-time transaction.

compared to the private market. The Fed was able to do so because, as a patient investor, it required a lower liquidity risk premium than private lenders.

We next focus on the adverse selection mechanism, which differs from the balance sheet mechanism in the role played by credit risk. The balance sheet mechanism focuses on "collaterizable" net worth (Bernanke and Gertler (1989)) and secured financing. While credit risk may trigger the initial funding shock, it plays no role in the amplification mechanism. Clearly though, in addition to this balance sheet effect, feedback from asymmetric information and credit risk are also potentially important amplification mechanisms in crisis periods. Indeed, as the crisis continued to evolve, concerns about the credit risk of financial institutions and bank capital came increasingly to the fore.

Amplifications from adverse selection appear to be particularly relevant for the later stages of the crisis. We provide a brief survey of the literature focusing mainly on those papers with explicit policy implications, particularly for the current crisis. The literature finds that private funding markets may break down when borrowers have private information about their asset values, as safe borrowers exit the market and lenders, faced with an adverse selection of risky borrowers, reduce their lending. The market failure provides a role for public liquidity supply. However, the literature is also skeptical of the efficacy of public intervention in the face of asymmetric information.

The Fed's crisis interventions evolved along with the changing nature of the crisis. The second stage Fed programs—the Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility (AMLF), Commercial Paper Funding Facility (CPFF), Money Market Investor Funding Facility (MMIFF), Term Asset-Backed Securities Loan Facility (TALF)—rolled out starting in September 2008 (top panel of Figure 1), went beyond providing liquidity and

addressed the funding needs of borrowers in select credit markets. With these facilities, the Fed accepted a certain amount of credit risk which it managed by appropriate selection of haircuts on the collateral put to it. The increased credit risk is due to the longer maturity of the loans (up to 5 years for TALF loans, for example), the non-recourse nature of the loan in the case of the AMLF and TALF facilities and the broader set of counterparties (any US company with eligible collateral can borrow at TALF, for example). Given the relatively later date of their introductions, examination of these programs and their effectiveness remains at an early stage.

In the final section of the paper, we provide fresh evidence on the effect of changes in the Fed's supply of liquidity on changes in the 3-month Libor-OIS spread, which is a measure of stress in funding markets. In contrast to previous work (which focus on announcement date effects), we examine changes in the amount outstanding of funds supplied by the Fed via the TAF and swap facilities. We control for credit risk, the uncertainty regarding credit risk, and liquidity risk, guided by the literature. We distinguish between periods of increasing supply and periods of decreasing supply of funds by the Fed and find that increases in supply tend to reduce interest rates during periods of high funding liquidity risk. Surprisingly, decreases in supply also appear to be associated with lower spreads. Moreover, the impact of the Fed's fund supply on the spread has decreased over time, a result that is helpful in evaluating the impact of the Fed's potential, future exit from its liquidity programs.

In the remainder of the paper we survey the literature on balance sheet and adverse selection amplification mechanisms and we interpret and evaluate the Fed's crisis interventions in terms of this literature. We provide new empirical evidence on the effect of increases and decreases in the Fed's supply of funds on the Libor-OIS spread. We end with some concluding remarks.

The Balance Sheet Amplification Mechanism

The focus of the literature on balance sheet mechanisms is on the principal agent problem between borrowers and lenders that arises from delegated investment. Households invest in hedge funds and mutual funds who invest in securities; these funds may, in turn, invest in more specialized investors with expertise in sophisticated trading strategies.[5] The principal agent problem is defined as a deviation from first best outcomes associated with the necessity of external financing (Bernanke and Gertler (1989)), and a consequence is that the intermediary's investments come to depend on external financing terms and its balance sheet conditions.

The balance sheet amplification channel involves a positive feedback between funding constraints and changes in assets values or cash flow of intermediaries. An early example is Bernanke and Gertler (1989) who show how funding shocks reduce borrowers' cash flows and impair their ability to finance investments from retained earnings, thereby increasing the cost of new investments. They propose a model where borrowers have better information about project quality than potential lenders.[6] The resulting agency cost creates a wedge between the borrower's costs of internal and external funds. Moreover, the external funds premium is greater when borrower net worth is lower, as in periods of financial distress. This inverse relationship arises because agency costs are higher when borrower cash flows are lower and consequently the external funds premium must be greater to compensate the lender. Reduced investments result in lower output and cash flows, creating a "financial accelerator" effect of cash flows on investments due to counter-cyclical agency costs.

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[5] For example, Fund of Funds is hedge funds that invest in other hedge funds.
[6] The superior information arises because the lender is assumed to pay a fixed auditing cost in order to observe the borrower's realized return whereas the borrower observes her return for free.

In literature subsequent to Bernanke and Gertler (1989), emphasis is placed on the effect of funding shocks on asset prices (instead of cash flows) which affect firm net worth through changes in the values of assets and liabilities (Kiyotaki and Moore (1997a), Shleifer and Vishny (1997), Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009)). Since asset prices are forward looking, persistent shocks that impact asset prices can have potentially large wealth effects.

The generic balance sheet constraint for time *t* can be expressed (following Krishnamurthy (2009)) as:

$$m_t \theta_t \leq w_t \tag{1}$$

where *m* is broadly interpreted as a "margin" requirement per unit of asset holding, θ is the number of units of assets, and *w* is the value of equity capital. This interpretation of *m* is consistent with Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009).[7] In words, the firm's equity capital must be sufficient to cover its total margins. Higher margins reduce asset prices which, in turn, lower *w* and cause the constraint to tighten further: this is the feedback loop between funding conditions and asset market prices.

An alternative interpretation of *m* is obtained from Kiyotaki and Moore (1997a), where lenders limit the debtor's investments based on pledged collateral. Suppose that borrowers pledge θ units of assets to borrow $\gamma\theta P$, where *P* is the asset price and $\gamma<1$. Then, the borrower's budget constraint is:

$$\theta_t P_t \leq \gamma \theta_t P_t + w_t \tag{2}$$

[7] Margin constraints are one (perhaps the most common) example of a balance sheet constraint, but other constraints are possible. For example, in He and Krishnamurthy (2008), incentive conflicts limit the amount of coinvestment by outsiders in a mutual fund.

Or, rewriting,

$$(1-\gamma)P_t\theta_t \leq w_t \qquad (3)$$

Here γ can be viewed as the "haircut" on the collateral. If we write m=(1-γ)P, then (3) and (1) are equivalent expressions of the budget constraint.

In Kiyotaki and Moore (1997a), credit constraints arise because borrowers can only borrow against assets that can be pledged as security for the loan. The pledgable assets serve a dual capacity: as factors of production and as collateral. An initial productivity shock reduces the net worth of constrained firms resulting in lower investments and lower prices of pledgable collateral assets. As asset prices fall, constrained firms suffer a capital loss on their collateral assets and the magnitude of this loss is large due to leverage. The subsequent reduction in borrowing capacity leads to further rounds of decreased investments, asset price reductions and borrower net worth.

While Bernanke and Gertler (1989) and Kiyotaki and Moore (1997a) are concerned with "collaterizable" net worth, they acknowledge but do not address the market liquidity of the collateral. This issue is addressed by Shleifer and Vishny (1997), Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009). These papers are also concerned with the two-way feedback between borrowing limits and asset prices present in Kiyotaki and Moore (1997a). In addition, however, they introduce the idea of a positive feedback between funding illiquidity and market illiquidity. Funding illiquidity is the marginal investor's scarcity value (or shadow cost) of capital. Market illiquidity is defined as the difference between the transactions price of a security and its fundamental value. The amplification mechanism discussed in these papers may be used to understand purely financial crises, independent of any effects on the real economy (for example, the stock market crash of 1987 and the LTCM crisis of 1998).

Shleifer and Vishny (1997) examine the effect of inter-temporal wealth constraints on the incentives of arbitrageurs to eliminate mispricings between two securities with identical cash flows. They consider the agency relationship between arbitrageurs with specialized market knowledge (e.g. hedge funds) and the investors who fund them (e.g. wealthy individuals, banks and endowments). If investors chase returns, then they are likely to withdraw capital from arbitrageurs when prices are falling. In turn, lacking capital, arbitrageurs are unable to reduce mispricing. This phenomenon is referred to as the "limits of arbitrage."

Gromb and Vayanos (2002) provide a welfare analysis of competitive arbitrage. In the process, they formalize many of the intuitions of Shleifer and Vishny (1997). The possibility of arbitrage arises because of segmented asset markets: some investors are able to invest in one risky asset but not in another (identical) risky asset. Arbitrageurs can invest in both assets and act as intermediaries: by exploiting price discrepancies, they facilitate trade among investors, effectively providing liquidity to them. In so doing, arbitrage activity benefits all investors. It is assumed that arbitrageurs must have separate margin accounts for the two assets (i.e. there is no cross-margining).[8] This implies that arbitrageur positions are wealth-constrained. Gromb and Vayanos (2002) show that if arbitrageur wealth changes are insufficient to cover variations in both margin accounts, then they may be unable to take a position large enough to eliminate price discrepancies. Further, arbitrageurs may choose not to invest up to their wealth constraint if the

[8] The authors argue that this assumption captures the notion that a custodian of the margin account in one market might refuse to accept a position in a different market as collateral. This assumption may not hold in all asset markets, however. For example, an arbitrageur with a simultaneous position in Treasury spot and futures markets generally cannot cross-margin.

capital gain from the arbitrage position is expected to be risky.[9] They can also increase price volatility by liquidating their positions in the event that price discrepancies widen further.

The feedback loop in Kiyotaki and Moore (1997a) and Gromb and Vayanos (2002) may be called an *illiquidity spiral*: reductions in collateral values result in lower asset prices and further reductions in collateral values. In terms of equation (3), the feedback is between θP and w, for given m. In comparison, Brunnermeier and Pedersen (2009) derive a *margin spiral* where lower asset prices reduce arbitrageur net worth via higher margins. In terms of equation (1), the feedback is between m and w, for given θ. While this distinction is useful for expositional reasons, changes in m and θ are clearly inter-dependent.

Brunnermeier and Pedersen (2009) examine the relationship between margin conditions and market illiquidity. In their model, customers with offsetting demand shocks arrive sequentially to the market. Speculators smooth the temporal order imbalance and thereby provide liquidity. The speculators borrow using collateral from financiers who set margins (defined as the difference between the security's price and its collateral value) to control their value-at-risk (VaR). Financiers can reset margins every period and so speculators face funding liquidity risk from the possibility of higher margins or losses on existing positions. A margin spiral occurs as follows. Suppose markets are initially highly illiquid and margins are increasing in market illiquidity.[10] A funding shock to the speculator lowers market liquidity and results in higher

[9] This follows from the possibility that the price discrepancy may grow wider and result in capital losses for arbitrageurs.

[10] This happens if financiers are unsure if price changes are due to news shocks or liquidity shocks, and if volatility is time-varying. Under these conditions, liquidity shocks leads to higher volatility which increases financiers' expectations of future volatility, and this in turn leads to higher margins. In contrast, if financiers know for sure that price changes are due to fundamental news shocks, they realize that prices will revert in the future, making arbitrage positions in the current period profitable. This reduces the incentives of financiers to increase margins when liquidity decreases.

margins which causes speculators to delever, further tightening their funding constraints. Therefore, market liquidity falls even further.

There is no default risk in balance sheet models as loans are fully collateralized.[11] Thus, the amplification works through fund flows and liquidity risk. That inefficiencies can arise in the absence of credit risk suggests the positive role of central banks to alleviate funding and capital constraints during periods of crisis.

Balance Sheet Amplification Mechanism: Implications for Central Banks

The welfare analysis of Gromb and Vayanos (2002) shows that arbitrageurs may fail to take an optimal level of risk, in part because they fail to internalize the effect of changing their positions on prices.[12] For example, arbitrageurs may under-invest in the arbitrage opportunity since they do not consider that larger positions in the current period would reduce price discrepancies in future periods. Thus, the key source of allocative inefficiency is the negative externality from changes of an arbitrageur's positions on other arbitrageurs.

An implication of Gromb and Vayanos (2002) is that regulatory intervention may affect arbitrageurs' financial constraints by reducing arbitrageurs' capital and margin requirements, or by providing financing to those institutions that provide capital to arbitrageurs.[13] Since the ex-

[11] This is explicit in Kiyotaki and Moore (1997a). Bernanke and Gertler (1989) indicate that their model is about "collaterizable" net worth. The models of Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) rule out default since margin accounts need to be fully collaterized.

[12] An important reason for arbitrageur position changes to be Pareto improving is that price changes causes wealth redistributions and that market segmentation implies that agents' marginal rates of substitutions differ (as has been pointed out in a general incomplete market setting by Geanakoplos and Polemarchikis (1986)). Arbitrageurs prefer to receive more wealth earlier and other investors prefer to receive wealth later, and this creates the potential for Pareto improving wealth redistributions across time and states.

[13] When regulators have limited control over financial constraints, they may prefer to tighten constraints in some cases to reduce overinvestment (e.g. by limiting entry into the arbitrage industry). Over investment arises if arbitrageurs are initially fully invested in the arbitrage opportunity. If other investors' demand increases, the price

ante choice of leverage may be sub-optimal, there is scope for prudential capital and liquidity requirements and, more generally, regulation of financial sector balance sheets. In addition, ex-post policy actions to address the allocative inefficiency should be welfare improving, although they need not be unanimously approved (due to distributional effects).

In Bernanke and Gertler (1990), the optimal policy is a "debtor bailout" whereby the government redistributes endowment (via lump sum taxes) from lenders to borrowers until the agency cost disappears. The policy works by directly addressing the problem of low net worth of borrowers (i.e. financial firms such as brokers, banks and clearing houses). Further, such transfers need not be direct but channeled through financial intermediaries, under the assumptions that the latter can identify legitimate borrowers and the government ensures that funds are channeled to successful projects. The moral hazard problem is addressed by recommending bailouts only in response to large aggregate or systemic shocks over which borrowers have no control.

Brunnermeier and Pedersen (2009) discuss the ability of central banks to enhance market liquidity by controlling funding liquidity. If the Central Bank is better at distinguishing news shocks and liquidity shocks and conveys this distinction to financiers, then the latter may ease their margin requirements. Alternatively, the Central Bank can directly ease speculator funding conditions during a crisis, either by providing emergency funding at lower margins, or by simply

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discrepancy increases and the arbitrageurs suffer capital loss on their current positions. If they reduce their positions, they will limit their loss and be able to provide liquidity in future periods by trading more aggressively, mitigating the price wedge.

stating its intention to do so. If the statement is credible, then financiers may loosen margin requirements since their worst-case scenarios have lower probability of occurrence.[14]

Federal Reserve as the Lender of Last Resort during the Early Stages of the Crisis

We now turn to an assessment of the Fed's ex-post interventions during the crisis, viewed through the prism of the balance sheet literature. From equations (1) and (3), we observe that a regulator has three types of instruments in its disposal:

- Reducing m, the required margins on new funds
- Increasing γ, the value of pledgable assets
- Increasing w, the equity capital

In the following, we will focus on the Fed's efforts to reduce m and increase γ during the early stages of the crisis. Traditional LOLR policies advocate lending to solvent institutions against good collateral at a penalty rate (Rochet and Vives (2004)). However, Cecchetti and Disyatat (2009) argue that, when there is generalized market failure, it may not make sense to provide liquidity at a penalty rate over the market since no particular institution is benefiting relative to others. They conclude that "...liquidity support will often, and probably should, be provided at a subsidized [relative to the market] rate when it involves an illiquid asset where a market price cannot be found."

Normally, the Fed provides reserves to a small number of primary dealers who distribute these reserves to banks via the interbank market; in turn, banks lend to ultimate borrowers.

[14] Allen, Carletti and Gale (2009) provide another rationale for Central Bank intervention. When markets are incomplete, they show that the price of the long-lived asset may exhibit excessive price volatility. By using open market operations appropriately to fix interest rates, the central bank can prevent the price volatility and implement the constrained efficient solution. Thus, the central bank effectively completes the market, and open market operations are sufficient to deal with systemic liquidity crises.

When the market is disrupted, the Fed relies on the discount window facility to provide short-term backup funding to eligible depository institutions. In the current crisis, interbank markets were dysfunctional, especially for term lending. The Fed encouraged banks to borrow from the discount window, but they were reluctant perhaps in part due to the "stigma" associated with such borrowing.[15]

Responding to these concerns, the Fed introduced a number of programs (the stage one programs) between December 2007 and March 2008, all designed to provide short-term liquidity to sound financial institutions.[16] In the context of the balance sheet literature, the Fed's stage one programs may be viewed as easing balance sheet constraints and thereby breaking the illiquidity spiral. An example is the TSLF which allows dealers to swap illiquid securities (say MBS) for liquid Treasury securities that the dealers can subsequently use as collateral to borrow funds. The dealer pays a smaller haircut (say H_Treasury) from borrowing against liquid Treasuries compared to what he pays (say H_Illiquid) when borrowing against illiquid securities. Of course, the TSLF also charges a haircut (say H_TSLF). As long as H_TSLF<(H_Illiquid - H_Treasury)), the dealer's net funding costs are lowered by the TSLF. Therefore, the TSLF may be viewed as increasing γ in equation (3).

Other of the Fed's stage one programs may be viewed as breaking the margin spiral (i.e. reducing *m* in equation (1)). The Fed's TAF auctioned credit to eligible depository institutions for a term of 28 days initially and up to 84 days by August 2008. A similar program, the PDCF,

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[15] For example, Furfine (2003) shows evidence consistent with potential borrowers staying away from the discount window, perhaps out of concern that such borrowing will be viewed as a sign of higher credit risk. Armantier, Ghysels, Sarkar, and Shrader (2009) provide evidence that discount window stigma existed throughout the financial crisis.

[16] See Armantier, Krieger and McAndrews (2008), Adrian, Burke and McAndrews (2009) and Fleming, Hrung and Keane (2009) for descriptions of TAF, PDCF and TSLF, respectively. For descriptions of other Fed programs, see http://www.federalreserve.gov/monetarypolicy/bst.htm.

issued credit to primary dealers. The international counterpart to TAF is the bilateral currency swap arrangements with foreign Central Banks allowing the latter to provide dollars to banks in their own jurisdictions. These programs may bring down *m* in two ways. It may provide financing where private financing is simply unavailable or, alternatively, where private financing is available in dearer terms.

How effective were these programs in reaching their objectives? We examine one liquidity risk proxy: the spread between overnight repo rates on mortgage backed securities (MBS) and Treasury securities.[17] Since both MBS and Treasury repo loans are collateralized and are issued for a short (overnight) maturity, the spread between them mainly reflects the relative illiquidity of the two assets. In particular, during the crisis, investors sought safety in the Treasury market while agency MBS securities became *relatively* illiquid, leading to an increase in the agency MBS-Treasury repo spread.[18] The repo markets are important for bank financing (Hordahl and King (2008)). In addition, if the secured financing market is stressed, it is highly likely that the unsecured financing market is also in trouble. For these reasons, the MBS-Treasury repo spread provides a good proxy for funding illiquidity in the economy (and not just in the secured financing markets).

The MBS-Treasury spread data comes from the Federal Reserve of New York's primary dealer survey. The trading desk at the New York Fed collects information each morning from dealers on the average overnight general collateral repo rate at which it has financed its positions

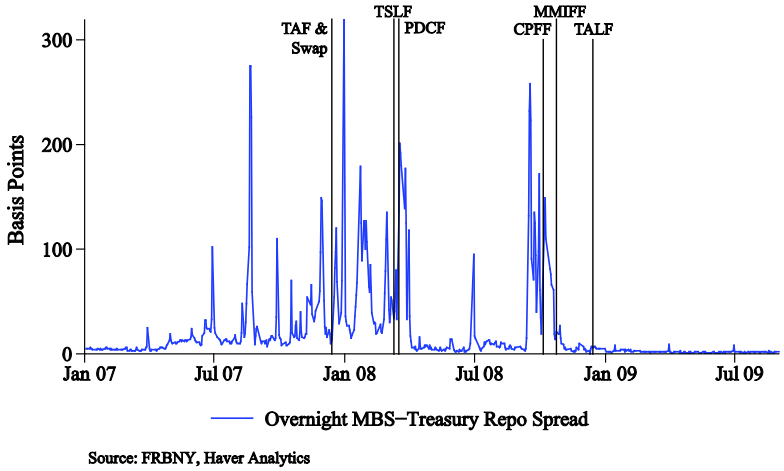
[17] These are general collateral (GC) repo rates that reference non-specific government securities with the lowest level of counterparty risk (Hordahl and King (2008)). In contrast, specific collateral rates reference particular types of collateral, such as an on-the-run bond.

[18] Brunnermeier (2009) uses the repo spread (although not of the overnight maturity) to illustrate liquidity risk during the crisis. Gorton and Metrick (2009) discuss the role of repo markets during the financial crisis.

in Treasury securities, agency debt securities, and agency MBS, as well as the quantity of securities financed. An overall weighted average is then calculated for each collateral type.

As evidence of the effectiveness of the TSLF and PDCF programs, the spread between overnight Agency MBS repo rates and the Treasury Collateral repo rates decreased after the TSLF program was implemented (Figure 2). Fleming, Hrung, and Keane (2009) show that this reduction is statistically significant. They further show that the narrowing of the repo spread is primarily attributable to increases in the Treasury repo rate and less so to decreases in the MBS repo rate. However, as the authors note, increases in the Treasury repo rate are important for the liquidity of the market.[19] Since the overnight repo spread may be attributed to the reduced collateral value (from lower market liquidity) of MBS relative to Treasuries, or, alternatively, the increased collateral value of Treasuries (from higher market liquidity) relative to MBS, the reduction in the spread suggests an increase in γ.

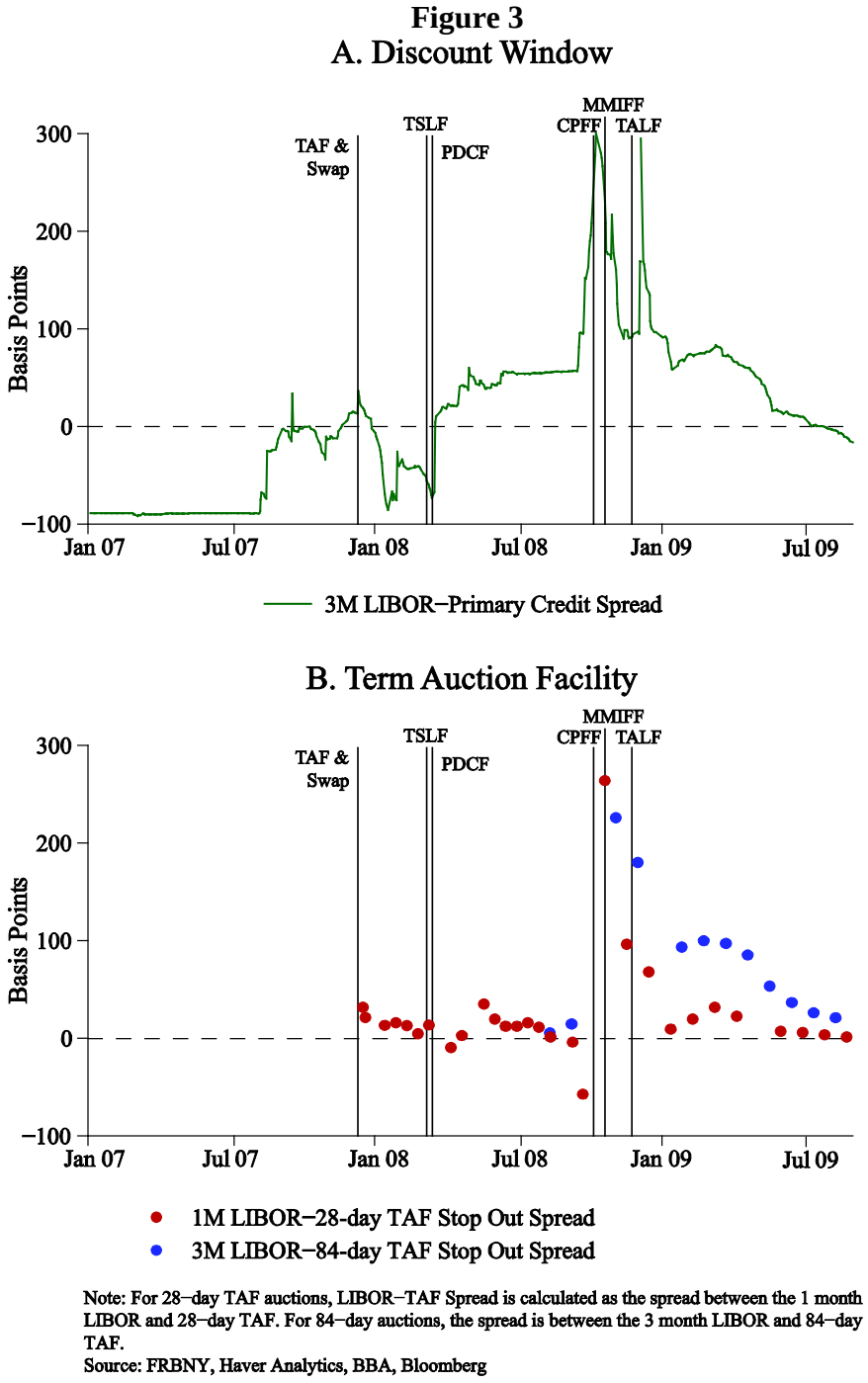
Figure 2
Liquidity Risk During the Crisis



Source: FRBNY, Haver Analytics

[19] Treasury securities are widely used as collateral for secured funding and so improved liquidity for Treasuries is likely to have a beneficial effect for secured funding rates in general. In addition, Fleming, Hrung, and Keane (2009) state that an "unusually low Treasury general collateral repo rate puts downward pressure on repo rates for individual Treasury securities, increasing the likelihood of settlement problems (see Fleming and Garbade (2004, 2005))."

Figure 3



Note: For 28−day TAF auctions, LIBOR−TAF Spread is calculated as the spread between the 1 month LIBOR and 28−day TAF. For 84−day auctions, the spread is between the 3 month LIBOR and 84−day TAF.
Source: FRBNY, Haver Analytics, BBA, Bloomberg

Figure 3.A shows the difference between LIBOR, which is taken to be the benchmark borrowing rate in private markets, and the Discount Window borrowing rate (i.e. the prime

rate).[20] We observe that the discount rate was initially above the LIBOR rate, which partly explains banks' reluctance to use the discount window in the initial stages of the crisis. Figure 3.B plots the difference between LIBOR and the stop out rates in the 28 and 84-day TAF auctions. We find that LIBOR generally exceeded the stop out rates, indicating that the Fed was successful in providing credit at below-market rates. In addition, evidence indicates that the TAF and the swap line programs reduced interest rate spreads.[21]

The success of the Fed in easing funding constraints during the crisis is likely to have had a beneficial effect on the real economy, via the channels suggested in Bernanke and Gertler (1989) and Kiyotaki and Moore (1997a). Del Negro, Eggertsson, Ferrero, Kiyotaki (2009) extend the model of Kiyotaki and Moore (2008), and study the impact of a large shock, of the order of magnitude observed in the financial crisis of 2008. Their model simulations suggest that these policy interventions prevented a repeat of the Great Depression in 2008-2009.

Adverse Selection Amplification Mechanisms and Implications for Central Banks

The first-stage programs exposed the Fed to minimal credit risk. The Fed's loans to banks and primary dealers through the various facilities are overcollaterized and made with recourse to the borrowing firm.[22] In the case of the currency swap lines, the foreign Central

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[20] The Libor rate is for unsecured funding while the prime rate and the stop out rate are for secured funding. However, much of the collateral posted to the Fed were illiquid and could not be used to obtain secured funding elsewhere. Therefore, the Libor rate closely approximates the opportunity cost of funds for TAF participants.

[21] McAndrews, Sarkar and Wang (2009) study the effect of TAF on the Libor-OIS spread. McAndrews (2009) and Coffey, Hrung and Sarkar (2009) study the effect of swap lines, the former on the Libor-Fed Funds spread and the latter on on deviations from Covered Interest Rate Parity. Cetorelli and Goldberg (2009) study the effect of liquidity programs on the internal capital markets of global banks.

[22] For a description of the required collaterals, see http://www.federalreserve.gov/monetarypolicy/bst_ratesetting.htm

Banks are responsible for payments; moreover, the Fed receives and holds an equivalent amount of foreign exchange for the dollars it provides to the Central Banks.

As the crisis continued to evolve, concerns about the credit risk of financial institutions and bank capital came increasingly to the fore. The Fed's stage one programs were dependent on solvent institutions to intermediate credit flow from the Fed to the economy.[23] As these intermediaries became impaired themselves, they were increasingly unwilling to lend. In addition, certain credit markets (such as commercial paper) became particularly afflicted. Consequently, the Fed decided to lend directly to some affected borrowers and markets. Thus, with its second stage programs, the Fed was forced to take on and manage a certain amount of credit risk.

To understand the intent behind these programs, we examine amplification mechanisms based on asymmetric information between borrowers and lenders. In contrast to the balance sheet amplifiers, the focus here is on the role of credit risk and the distribution of credit risk across borrowers. The papers surveyed below find a role for central bank intervention when adverse selection problems lead to market breakdowns. However, they also raise concerns that public liquidity provision might crowd out private liquidity.

Heider, Hoerova and Holthausen (2009) build a model of unsecured interbank markets with asymmetric information regarding counterparty risk.[24] Banks need liquidity as customers may withdraw deposits on demand (as in Diamond and Dybvig (1983)). The interbank market

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[23] The objective of the Fed was to improve the distribution of liquidity across financial intermediaries, as stated in the announcement of the TAF program on December 12, 2007 (available here: http://www.federalreserve.gov/newsevents/press/monetary/20071212a.htm). This objective could not have been achieved by a generalized injection of liquidity such as through the purchase of Treasury debt.

[24] Flannery (1996) also studies asymmetric information problems and identifies a "winner's curse" problem facing new lenders in banking markets. He shows that private loan markets can fail because lenders become less certain how to distinguish between illiquid and insolvent banks.

distributes funding from banks with excess reserve balances to those with a reserve shortage. Counterparty risk exists since banks have risky long-term assets and may be unable to repay their interbank loans. Asymmetric information about counterparty risk exists because banks have private information about the riskiness of their long-term assets.

The authors show that different regimes occur in the interbank market depending on the level and distribution of counterparty risk. Since lenders cannot distinguish between safe and risky banks, the interest rate contains a risk premium. In the good regime, the risk premium is small compared to the opportunity cost of funds and so the interbank market performs smoothly with low interest rates. If, on the other hand, the risk premium is too high, then safe borrowers exit the interbank market. Consequently, in this regime, lenders face an adverse selection of risky borrowers and the interest rate is high. In the worst regime, both the level and the dispersion in credit risk[25] are high, and as a result the interbank market stops functioning. Either lenders find it unprofitable to lend (even at high interest rates) and hoard funds[26] or, alternatively, risky borrowers find the interest rate too high and drop out.

What are the implications of the model for central bank liquidity supply? [27] Suppose credit risk increases unexpectedly and lenders face an adverse selection of borrowers (but the

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[25] If p_s (p_r) is the probability that the long term investment has a higher (lower) than expected chance of success, then dispersion is defined as p_s- p_r.

[26] Liquidity hoarding can also arise if banks fear they will be unable to finance projects and trading strategies due to uncertainty in the aggregate demand for liquidity (Allen, Carletti and Gale (2009)). In such a case, Central Bank intervention may not be needed since banks hold sufficient liquidity to meet their own needs without accessing the interbank markets (Allen and Carletti (2008)).

[27] There is a vast literature on central bank or government intervention to address market failures in the face of asymmetric information, moral hazard and monopoly power. Holmstrom and Tirole (1998) and Diamond and Rajan (2005) analyze the optimal (public) provision of liquidity when interbank markets face aggregate liquidity shocks and contagious failures generated by the illiquidity of bank assets. Gorton and Huang (2006) rationalize the LOLR function of central banks with the need of monitoring banks and providing them with liquidity during crises in order to prevent inefficient panics. Acharya, Gromb and Yorulmazer (2008) examine how the strategic power of an inter-

market is still functioning). If the central bank has the same information as the market, it can offer liquidity to all banks at the highest interest rate that safe banks are willing to borrow. As in Flannery (1996), this rate is at a discount relative to the market rate and the public supply of liquidity mitigates the private liquidity shortage. The cost is that the central bank does not distinguish between sound and risky institutions, a concern also raised by Goodfriend and King (1988). Moreover, the private supply of liquidity is crowded out.

Bolton, Santos and Scheinkman (2009) also raise the possibility that public liquidity may crowd out private liquidity. [28] In their model, there are two types of investors, short-run (SR) who invest in valuable risky projects that typically mature early, and long-run (LR) who invest in higher return long-term assets. The ex-ante efficient solution is for SRs to sell risky assets to LRs (i.e. to obtain 'outside' liquidity) and for trading not to occur too quickly. However, SRs have private information about the assets. If investors are concerned about adverse selection problems that undermine secondary markets in the future then they may trade too soon and at fire sale prices.

A central bank may step in and provide liquidity (in the form of price support) to mitigate the fire sale. The effectiveness of liquidity supply depends on whether the central bank can accurately time its supply of liquidity. If it delays liquidity provision, it crowds out outside liquidity and undermines the incentives of SRs to obtain outside liquidity by selling assets for

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bank lender might force a liquidity-constrained borrower to sell at fire sale prices. The strategic power is the market failure that justifies Central Bank intervention.

[28] Bolton, Santos, and Scheinkman (2009) build on the literature that integrates financial intermediaries and securities markets in a single framework. In Diamond (1997) banks coexist with securities markets since households face costs in switching between banks and securities markets. Fecht (2004) introduces segmentation on the asset side between financial intermediaries' investments in firms and claims issued directly by firms to investors though securities markets. Allen and Gale (2004) introduce securities markets into a general equilibrium theory of institutions. Intermediaries provide liquidity insurance, as in Diamond and Dybvig (1983), and risk sharing services by packaging existing claims for investors without access to markets. The financial system is efficient as long as markets are complete.

cash. However, if it supplies liquidity quickly, then public liquidity can complement private liquidity. In this case, the central bank plays the role of market maker of last resort by inducing SR traders to obtain liquidity through asset sales.

Adverse Selection and the Fed's Actions during the Later Stages of the Crisis

The Fed's second stage programs were designed to provide funding in a targeted manner to borrowers and investors in key credit markets (Bernanke (2009)). These programs, rolled out starting in September 2008 (see Figure 1), came in two flavors. Continuing its LOLR role, the Fed provided a liquidity backstop to money market mutual funds (MMMF) and to commercial paper (CP) borrowers. The Fed developed a facility to finance bank purchases of high-grade asset-backed CP from MMMFs which helped the latter to meet redemption demands without having to sell assets at distress prices. Another Fed facility was to buy high-quality (A1-P1) CP at a term of three months which reduced the risk that CP borrowers could not roll over maturing issues.

The second flavor of Fed programs went beyond providing liquidity and addressed the funding needs of borrowers in select asset-backed markets. In a joint effort with Treasury, the TALF provides three-year or five-year term loans to investors against (mostly) new issuances of AAA-rated securities. With the Treasury providing funding, this facility allows the Fed to accept a certain amount of credit risk. The Fed manages the credit risk by appropriate selection of haircuts on the collateral put to it. The objective of the program is to revive private lending by enabling lenders to securitize new loans. In addition, by stimulating market activity, the facility potentially increases the valuation of existing loans by reducing the illiquidity premium.

The design of the TALF program appears to address the concern that the Fed might crowd out the private supply of liquidity in the affected markets. The program leverages private originations of asset backed securities, consistent with Bolton, Santos, Scheinkman (2009). Further, the program offers funding at different rates for different asset classes (since the haircuts differ by asset). This feature appears to alleviate the moral hazard problems inherent in offering a flat rate to all investors independent of their credit risk, which is the concern raised by Goodfriend and King (1988) and Heider, Hoerova, and Holthausen (2009).

Given the relative newness of these programs, rigorous empirical evidence about their effectiveness is scarce. An exception is Ashcraft, Garleanu and Pedersen (2009) who report the results of a survey of financial institutions to see how their bid prices for securities depend on the financing the Fed would offer. By offering loans at lower margins than the market, the Fed effectively lowers the required return for holding securities put to TALF. Consistent with this idea, the surveyed bid price increases as the Fed reduces its offered margins. This evidence is consistent with the expected effect on asset prices of lower margins.

Evolution of Credit and Liquidity Risk During the Crisis

As the crisis progressed, the relative importance of the balance sheet and adverse selection mechanisms likely changed. This evolution is implicit in the timing of the Fed's responses. In particular, the Fed's stage one programs emphasized the provision of liquidity to solvent institutions, implying that at this early stage of the crisis the Fed viewed access to funding as a greater risk to the economy than counterparty credit risk. In contrast, the second stage programs reflected the Fed's views of the increasing importance of credit risk. In this

section, we estimate proxies for liquidity risk, credit risk, and the distribution of credit risk across banks to examine the changing importance of the financial mechanisms over time.

The adverse selection effects operate via credit risk and its distribution across banks (Heider, Hoerlova, Holthausen (2009)). The credit risk measures considered here are the CDX IG index of CDS spreads and the dispersion in LIBOR panel quotes. The CDX IG index is composed of spreads on 5-year CDS contracts for 125 North American companies and provides information on the average default risk of major global firms. Because the CDX index tends to rise with increases in the level of economy-wide credit risk, we expect a positive relationship between CDX and adverse selection.

The LIBOR panel dispersion, defined as the difference between the maximum and minimum 3-month quote of the 16 LIBOR panel banks on each day, proxies for uncertainty about counterparty credit risk. The quote dispersion shows the extent to which some LIBOR panel banks report greater borrowing costs, indicating higher counterparty risk, compared to the typical LIBOR panel bank. Our uncertainty measure is consistent with those proposed in Heider, Hoerova, Holthausen (2009) and Pritsker (2009) (i.e. the spread in default probabilities assigned by lenders to a borrower's investments). Again, the expected relationship between the quote dispersion and adverse selection is positive. CDX comes from Markit and the LIBOR panel quotes come from the British Banker's Association via Bloomberg.

Balance sheet effects operate via illiquidity and margin conditions. As a measure of liquidity risk, we use the spread between overnight repo rates on MBS and Treasury securities. The spread primarily reflects the relative illiquidity of MBS relative to Treasuries and is minimally affected by credit risk, as discussed earlier. We compare the evolution of this spread with the evolution of our credit risk measures.

We compare these series to the 3-month spread between LIBOR and overnight indexed swap (OIS) rate, or Libor-OIS spread, which contains credit and non-credit risk premia. LIBOR is a benchmark unsecured interbank interest rate that is published by the British Bankers Association (BBA). OIS represents the expected average of the overnight fed funds rate over the term of the loan. This spread is widely used as a measure of stress in the interbank market. Arbitrage should normally ensure that the spread is close to zero, but the spread has widened dramatically during the crisis, as shown in Figure 3.[29] The variable considered here takes LIBOR quotes reported on day *t+1* and the OIS rate reported on date *t*, both at a term of 3 months. We use *t+1* LIBOR rates because the rate is fixed each morning at 11:00 am London time while the OIS rate is determined at the end of the business day US Eastern Time.

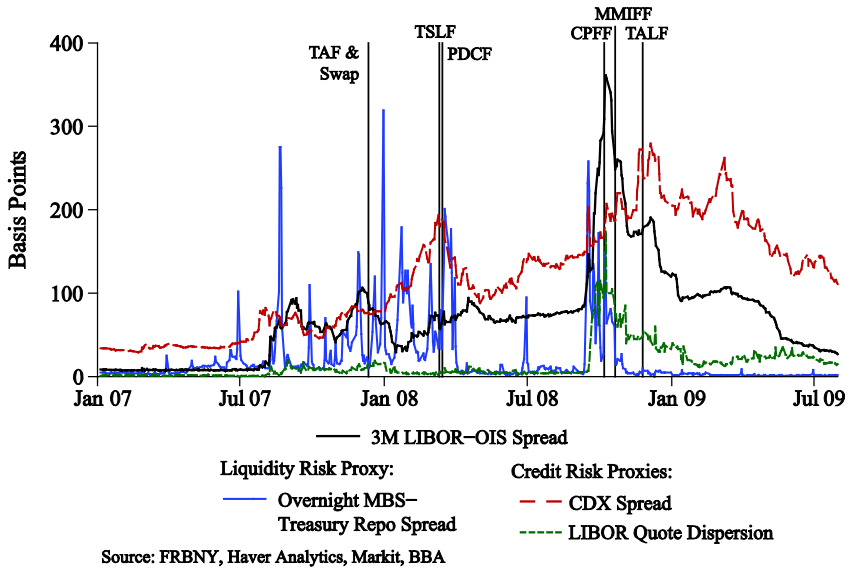
Figure 4 illustrates the evolution of liquidity risk (the MBS-Treasury repo spread) and credit risk (CDX and LIBOR quote dispersion) during the crisis, along with the Libor-OIS spread. All values are in basis points.

The evolution of risk proxies are consistent with the view that, at the beginning of the crisis, liquidity risk was relatively more important than credit risk, but that credit risk became more prominent as the crisis progressed, gaining particular importance after April 2008 and especially during September 2008. The initial months of the crisis were characterized by large spikes in liquidity risk but only a modest rise in credit risk. After April 2008, however, liquidity risk fell while the CDX spread remained elevated. After mid-September 2008, both types of risk increased, but the two credit risk proxies increased relatively more and remained elevated for a longer period of time.

[29] The two legs of the arbitrage are: loan $X for (say) 3 months; then fund the loan by borrowing $X each day in the fed funds market and, finally, hedge the interest rate risk by purchasing an OIS contract (Gorton and Metrick (2009)).

The Libor-OIS spread appears to co-move with both the credit and liquidity risk variables during the crisis period. We examine changes in the Libor-OIS spread more formally in the next section.

Figure 4
Risk Evolution During the Crisis



Effectiveness of the Fed's Liquidity Supply: Methodology

In this section, we investigate the relationship between the Libor-OIS spread and the supply of funds through the Fed's TAF and swap facilities. We focus on the latter facilities because they are the longest-running of the new facilities introduced by the Fed during the crisis, and because both facilities were meant to provide dollar funding to the interbank market (in contrast to other stage one liquidity programs such as the TSLF).

We interpret TAF and swap programs as primarily intending to decrease liquidity risk. Since the Libor-OIS spread contains credit and non-credit risk components, we control for credit risk to obtain meaningful correlations between the spread and the supply of funds by the Fed. To isolate the supply effects, we consider changes in their amount outstanding which are the net

effect of changes in the supply of funds by the Fed and repayment of funds by participating banks. During the first 10 months of the TAF's operation, the Fed raised the maximum amount offered at the TAF auctions four times, introduced longer-term auctions, and increased the auctions frequency. The swap facility underwent similar changes such as increases in size and changes in frequency. These changes mainly worked to increase the size of the programs. More recently, the Fed has been decreasing the size of these programs.

Our maintained assumption is that changes in the TAF and swap amount outstanding are exogenous. Before October 2008, the Fed and other central banks determined the maximum offering amount for the TAF and swap lines well in advance of the auctions, and banks fully subscribed to each auction. Thus, changes in the amount outstanding for these facilities were not influenced by market conditions concurrent with the supply announcement dates. Although the offer amounts were known in advance, there remained uncertainty about whether the auctions would be fully subscribed and, therefore, changes in amount outstanding were not fully anticipated by banks. We calculate changes in the amount outstanding to occur on the day that they were disclosed rather than the date of disbursement of funds (generally two days later) to maximize the "news" content in our measure.

Since October 2008, the TAF offer amount was increased to $150 billion per auction and the auctions became undersubscribed. At almost the same time, the swap lines were uncapped and foreign banks were allowed to bid for as much funds as they wanted. These changes meant that market conditions around auction dates likely played a larger role in determining the actual amount of funds disbursed. For this reason, endogeneity problems are likely greater since October 2008. To mitigate this concern, we include the Treasury-MBS GC repo spread to help control for changes in banks' demand for TAF and swap loans.

McAndrews, Sarkar, Wang (2009) decompose the Libor-OIS spread into its credit risk and non-credit risk components for the period from January 2007 to April 2008. They find that non-credit risk component was the major part of the Libor-OIS spread in 2007. The credit risk component of the spread was high and volatile in 2008. However, since the credit default swap (CDS) market became highly illiquid at this time, part of the credit risk component is likely to reflect liquidity risk as well. Consistent with the importance of liquidity risk, McAndrews, Sarkar, Wang (2009) find that the Fed's announcements of new supply of TAF funds significantly reduced the Libor-OIS spread during their sample period.

We differ from the approach in McAndrews, Sarkar, Wang (2009) in four primary respects. First, we use changes in actual *supply* of funds through the TAF and swap facilities rather than announcement dates. The amount outstanding variable, being continuous, is able to capture variations in the supply changes unlike the auction date variables used by McAndrews, Sarkar, Wang (2009) which are binary. We also examine a longer time series which allows us to examine recent decreases in the size of these facilities, potentially allowing us to draw implications for the Fed's exit strategies from these programs. Third, we look at the TAF and swap facilities simultaneously. Examining these two facilities together is natural because of their high degree of similarity. Both are intended to provide dollar funding to a broad range of counterparties, both were introduced simultaneously and relatively early in the crisis, and the timing, term, and magnitude of auctions for both facilities correspond closely. Finally, we employ an expanded set of covariates to control for credit and liquidity risk.

We examine interactions between four time period binary variables and the TAF and swap amount outstanding to allow for changes in the importance of liquidity risk over time.[30] The periods are chosen to correspond to the turning points of the crisis and to encompass TAF and swap auctions that occurred around these turning points. Period 1 starts on August 1, 2007, roughly the beginning of the crisis, and ends on March 9, 2008. Period 2 begins on March 10, 2008, the date of the last TAF auction before the acquisition of Bear Stearns by JPMorgan Chase and ends on September 9, 2008. Period 3 captures the Lehman bankruptcy and its aftermath, beginning on September 10, 2008 and ending on December 31, 2008. The final period runs from January 1, 2009 through July 31, 2009, a period when markets were normalizing.

We estimate the following equation, where Δ stands for the daily change in the variable:

$$\begin{aligned}\Delta(\text{Libor-OIS})_t = {} & \beta_1 + \beta_2 \Delta TAF_t * Period1 + \beta_3 \Delta TAF_t * Period2 + \beta_4 \Delta TAF_t * Period3 + \\ & \beta_5 \Delta TAF_t * Period4 + \beta_6 \Delta SWAP_t * Period1 + \beta_7 \Delta SWAP_t * Period2 + \\ & \beta_8 \Delta SWAP_t * Period3 + \beta_9 \Delta SWAP_t * Period4 + \beta_{10} \Delta CDX_t + \beta_{11} \Delta LIBOR\_DISP_t \\ & + \beta_{12} \Delta VIX_t + \beta_{13} \Delta MBS\text{-}TRSY\_REPO_t + \varepsilon_t\end{aligned} \quad (4)$$

This equation relates changes in the Libor-OIS spread to changes in amount outstanding at the Fed's TAF (denoted ΔTAF) and swap (denoted $\Delta SWAP$) facilities. We control for credit risk using the CDX index (ΔCDX) and the LIBOR quote dispersion variable ($\Delta LIBOR\_DISP$). We control for general market risk using options-implied volatility in the equity market (ΔVIX). Since VIX has been found to be a significant determinant of asset prices in several markets, we use VIX to account for financial market risk broadly.[31] Finally, we control for banks' balance

[30] It is possible that the effect of risk variables on the LBIOR-OIS spread also changes over time. Unreported results from regressions allowing for the risk variable coefficients to vary over different crisis periods indicate no qualitative changes to our estimates for amount outstanding of the TAF and swap variables.

[31] VIX has been found to be a significant determinant of prices of foreign exchange (Brunnermeier, Nagel and Pedersen (2008)), and sovereign CDS (Longstaff, Pan, Pedersen and Singleton (2007)).

sheet funding risk with the overnight MBS-Treasury repo spread (Δ*MBS-TRSY_REPO*). We use changes in variables to account for deterministic time-series effects (such as trends). All variables are summarized in Table I. TAF auction results are from the Federal Reserve Board website, and swap line results are from participating central bank websites.[32] VIX data is obtained from Bloomberg.

Table I: Variables Used in Regressions

Variable Name	Variable Description	Units
3 Month Libor-OIS Spread on date t	3 month LIBOR rate on date t+1 minus 3 month OIS rate on date t	basis points
TAF Outstanding	Outstanding value of TAF funds on award announcement date	billions USD
Non-Negative Component of TAF Outstanding	Equal to the maximum of TAF outstanding and 0)	billions USD
Non-Positive Component of TAF Outstanding	Minimum of 0 and TAF outstanding	billions USD
Swap Outstanding	Outstanding value of all swap lines on award announcement date	billions USD
Non-Negative Component of Swap Outstanding	Maximum of Swap outstanding and 0	billions USD
Non-Positive Component of Swap Outstanding	Minimum of 0 and Swap Outstanding	billions USD
Period 1	Binary variable equal to 1 for dates between August 1, 2007 and March 9, 2008 and 0 otherwise	---
Period 2	Binary variable equal to 1 for dates between March 10, 2008 and September 9, 2008 and 0 otherwise	---
Period 3	Binary variable equal to 1 for dates between September 10, 2008 and December 31, 2008 and 0 otherwise	---
Period 4	Binary variable equal to 1 for dates between January 2, 2009 and July 31, 2009 and 0 otherwise	---
CDX Spread	CDX IG index	basis points
3M LIBOR Quote Dispersion on date t	Difference between maximum and minimum quote of banks in 3-month LIBOR panel on date t+1	basis points
VIX	Options implied volatility in equities market	basis points
Overnight MBS-Treasury Spread	Overnight MBS rate minus the Treasury GC repo rate	basis points

[32] Federal Reserve Board TAF information: http://www.federalreserve.gov/monetarypolicy/taf.htm
Foreign central bank websites: http://www.ecb.int/mopo/implement/omo/html/index.en.html
http://www.snb.ch/en/ifor/finmkt/id/finmkt_usdollars?LIST=lid1&EXPAND=lid1&START=1
http://www.bankofengland.co.uk/markets/other/dollarrepo/index.htm
http://www.boj.or.jp/en/type/release/adhoc/mok0812b.pdf
http://www.rba.gov.au/MarketOperations/Domestic/ExcelFiles/usd_repos.xls
http://www.riksbank.com/templates/ItemList.aspx?id=30117
http://www.norges-bank.no/templates/pagelisting____73626.aspx
http://www.nationalbanken.dk/DNUK/MarketInfo.nsf/side/USD_auction!OpenDocument
http://www.bok.or.kr/broadcast.action?menuNaviId=1562
http://www.banxico.org.mx/sitioingles/portalesEspecializados/tiposCambio/US_dollar_auctions_results.html

In a related regression, we decompose the TAF and swap lines amount outstanding into positive and negative changes. To be specific, we replace ΔTAF in (4) with the following terms:

$$\Delta TAFP = max(0, \Delta TAF), \text{ and } \Delta TAFN = min(0, \Delta TAF)$$

Further, we replace $\Delta SWAP$ in (4) with the following terms:

$$\Delta SWAPP = max(0, \Delta SWAP), \text{ and } \Delta SWAPN = min(0, \Delta SWAP).$$

The balance sheet constraint is predicted to bind on the down side (i.e. when intermediaries are capital constrained) but not on the up side (i.e. when capital is widely available). This predicted asymmetry implies that increases in the supply of funds by the Fed should decrease spreads whereas reductions in the supply should have little impact on the spread.

Effectiveness of the Fed's Liquidity Supply: Results

Table II shows results from estimating equation (4). The results indicate that the supply of funds from both the TAF and the swap line programs were associated with a reduction in the Libor-OIS spread during the early phase of the crisis (i.e. up to March 9, 2008). In particular, an increase of $1 billion in the supply of TAF and swap line funds outstanding is associated with an average decline in the Libor-OIS spread of 0.1 to 0.5 basis points during this time period. This result is consistent with the operation of the balance sheet amplification mechanism in the early stages of the crisis.

Table II: Changes in Amount Outstanding at Fed Facilities and the Libor-OIS Spread: August 2007-July 2009

Dependent Variable = Change in 3M Libor-OIS Spread

Explanatory Variables	Coefficient (S.E.)
Change in TAF Outstanding	
Period 1: 1 Aug 2007 - 9 Mar 2008	-0.130***
	(0.037)

Period 2: 10 Mar 2008 - 9 Sep 2008	-0.167
	(0.110)
Period 3: 10 Sep 2008 - 31 Dec 2008	-0.031
	(0.036)
Period 4: 2 Jan 2009 - 31 Jul 2009	0.009
	(0.018)
Change in Swap Outstanding	
Period 1: 1 Aug 2007 - 9 Mar 2008	-0.481***
	(0.150)
Period 2: 10 Mar 2008 - 9 Sep 2008	0.048
	(0.065)
Period 3: 10 Sep 2008 - 31 Dec 2008	-0.047
	(0.064)
Period 4: 2 Jan 2009 - 31 Jul 2009	0.019
	(0.016)
Credit Risk	
Change in CDX Spread	0.140***
	(0.042)
Change in 3M LIBOR Quote Dispersion	0.160***
	(0.050)
Liquidity Risk	
Change in Overnight MBS-Treasury Spread	0.025*
	(0.014)
Market Risk	
Change in VIX	0.511***
	(0.139)
Constant	0.091
	(0.286)
Adjusted R-squared	0.17
Observations	607

Note: Newey-West standard errors (five lags) in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Full sample is daily observations from January 3 2007 to July 31 2009. See Table I for a description of all variables.

During subsequent periods, we find that the supply of TAF and swap funds are not significant predictors of the interest rate spread. The sign of the TAF supply coefficient remains negative in periods 2 and 3, but it is not significant.[33] In the next section, we show that this apparent lack of significance may be due to an averaging of the separate effects of increases and

[33] The difference between the TAF coefficient in the early crisis period (i.e. period 1) and the second period is not statistically significantly, but the period 1 coefficient is significantly different from the estimates for periods 3 and 4. The early crisis swap coefficient is significantly different from all later swap coefficients.

decreases of the supply of funds. The sign of the swap line coefficient is negative in periods 1 and 3. Overall, considering the TAF and swap line results together, we conclude that the supply of liquidity by the Fed was most effective in the early stages of the crisis and the effectiveness moderated over time.

The credit risk variables are of the expected sign, with the LIBOR quote dispersion and the CDX spread being positively and significantly associated with the Libor-OIS spread. A 1 basis point change in either credit risk variable is associated with about a 0.15 basis point change in the Libor-OIS spread.[34] The overnight repo spread is also positively associated with the Libor-OIS spread during the crisis, but the estimate is only significant at the10% level. As discussed earlier, the marginal significance of the repo spread might be explained by the Fed's action to reduce the spread through the PDCF and TSLF facilities. Finally, changes in VIX are also significantly and positively associated with the Libor-OIS spread.[35]

Results from the regressions provide an indication as to when the Fed might expect its liquidity facilities to help improve funding conditions. Comparing the coefficient estimates and Figure 4, we observe that the facilities were most effective during periods of high liquidity risk and relatively low credit risk. The facilities did not appear to be effective during periods of extremely elevated credit risk such as the months just after the Lehman failure in 2008 and periods of low liquidity risk such as the first half of 2009. This is consistent with the stated intentions of the TAF and SWAP facilities, which is to provide short-term funding to banks. As such, these facilities are not expected to have a direct effect on the credit risk of banks.

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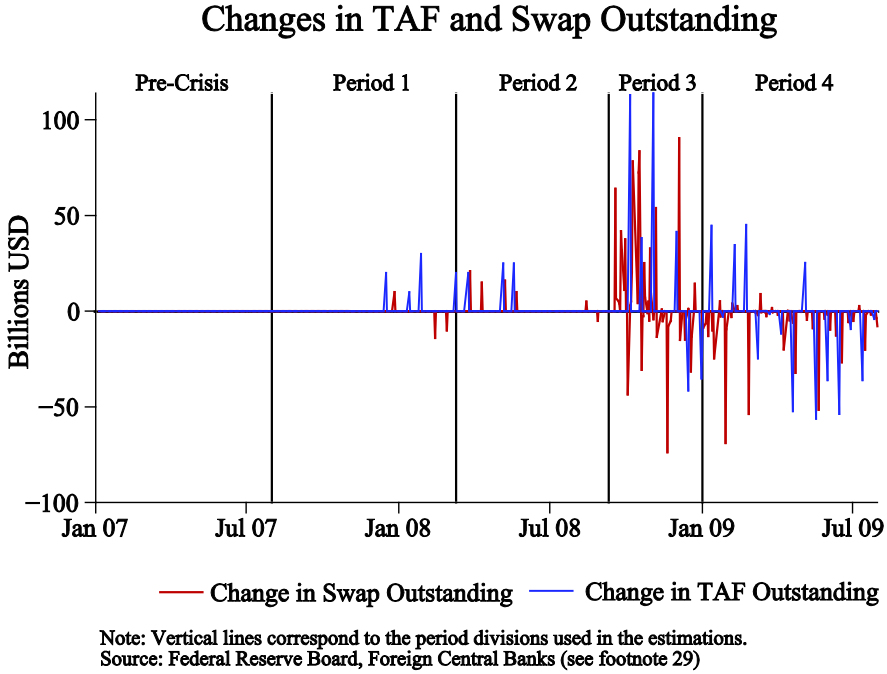
[34] Similar specifications with indices of LIBOR bank CDS spreads instead of the CDX index yielded highly similar results for the TAF and swap variables of interest, but the LIBOR-based indices were insignificant.

[35] We also considered the term premium, defined as the spread between the 5 year and 2 year on-the-run treasury yields, but this variable was not a significant predictor of the Libor-OIS spread.

Asymmetric Market Responses to the Fed's Liquidity Supply

We next report estimates using TAF and swap outstanding variables decomposed into positive and negative changes. Figure 5 shows the time series plots of the two main variables of interest–changes in TAF and swap outstanding. Note that the TAF has experienced negative changes in amount outstanding since the third period, while the swap lines have experienced both increases and decreases during each period since the crisis began. The share of negative changes in the TAF and swap lines combined, compared to the total number of changes, is small in periods 1 and 2, and rises to 40% in period 3 and 80% in period 4.

Figure 5



Note: Vertical lines correspond to the period divisions used in the estimations.
Source: Federal Reserve Board, Foreign Central Banks (see footnote 29)

The results from the estimation of the second regression are presented in Table III. *Symmetric* responses of the Libor-OIS spread are indicated by negative changes to both increases and decreases in the amount outstanding—i.e. reductions (increases) in the spread in response to a decrease (increase) in the amount outstanding. By comparison, *asymmetric* responses are

indicated by different signs of the coefficient depending on whether the change in amount outstanding is positive or negative.

In the pre-Bear period (Period 1), expansion of the TAF and swap lines in the early part of the crisis tended to be associated with a reduction in the Libor-OIS spread, consistent with prior results. Further, reductions in the swap line amount outstanding resulted in an increase in the spread. Therefore, the effect of Fed funds supply is symmetric during this period.

In contrast, during the post-Lehman periods (Periods 3 and 4), the effect of liquidity supply by the Fed is asymmetric. In particular, decreases in the TAF and swaps outstanding are associated with declines in the Libor-OIS spread whereas increases in the TAF and swap lines are also associated with decreases in the spread during this period. These results are statistically significant for changes in TAF outstanding. This asymmetry suggests that the lack of significance in the overall TAF coefficients during periods 3 and 4 in Table II may be due to an averaging of the positive and negative changes (which are of roughly equal magnitude). Hence, to understand responses of interest rates to changes in the supply of funds by the Fed during the post-Lehman period, it is important to account for this asymmetry.

Table III: Positive and Negative Changes in Amount Outstanding at Fed Facilities: August 2007-July 2009

Dependent Variable = Change in 3M Libor-OIS Spread

Explanatory Variables	Coefficient (S.E.)
Positive Changes in TAF Outstanding	
Period 1: 1 Aug 2007 - 9 Mar 2008	-0.093**
	(0.045)
Period 2: 10 Mar 2008 - 9 Sep 2008	-0.033
	(0.078)
Period 3: 10 Sep 2008 - 31 Dec 2008	-0.134***
	(0.020)
Period 4: 2 Jan 2009 - 31 Jul 2009	-0.108**
	(0.045)
Negative Changes in TAF Outstanding	
Period 3: 10 Sep 2008 - 31 Dec 2008	0.150***

	(0.016)
Period 4: 2 Jan 2009 - 31 Jul 2009	0.034**
	(0.015)
Positive Changes in Swap Outstanding	
Period 1: 1 Aug 2007 - 9 Mar 2008	-0.957***
	(0.050)
Period 2: 10 Mar 2008 - 9 Sep 2008	0.036
	(0.066)
Period 3: 10 Sep 2008 - 31 Dec 2008	-0.084
	(0.083)
Period 4: 2 Jan 2009 - 31 Jul 2009	0.204
	(0.161)
Negative Changes in Swap Outstanding	
Period 1: 1 Aug 2007 - 9 Mar 2008	-0.304***
	(0.036)
Period 2: 10 Mar 2008 - 9 Sep 2008	-0.087*
	(0.050)
Period 3: 10 Sep 2008 - 31 Dec 2008	0.063
	(0.045)
Period 4: 2 Jan 2009 - 31 Jul 2009	0.021
	(0.015)
Constant	0.252
	(0.264)
Risk Variables Included?	YES
Adjusted R-squared	0.19
Observations	475

Note: Newey-West standard errors (five lags) in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Negative changes in TAF outstanding did not occur until period 2. Full sample is daily observations from January 3 2007 to July 31 2009. See Table I for a description of all variables.

The existence of balance sheet constraints that bind only on the downside implies a negative relationship between the Libor-OIS spread and positive changes in TAF and swap lines and no relationship for negative changes. We find, however, that declines in the amount of TAF outstanding actually improved the Libor-OIS spread in periods 3 and 4. This association might reflect reduced pressure on funding markets at this time, leading to declining demand at the Fed facilities and a reduced spread. Indeed, the two declines in the TAF outstanding during period 3 occur during December 2008, when risk factors were already beginning to normalize. Referring

to Figure 4, one can see that by December 2008, liquidity risk had declined and so had the LIBOR quote dispersion, although the CDX index remained elevated.

The results from Table III also shed light on the issue of the Fed's exit strategy from these programs. First, the fall in outstanding value that has occurred since the beginning of 2009 likely reflects a return by participants to market sources for funding as interbank market rates have fallen. Figure 3 supports this view, showing that the spread between LIBOR and the Fed facilities has been steadily falling since early 2009. This view is further supported by the coefficient estimates on the negative changes in TAF and swap outstanding in 2009 (Table III) indicating that the reductions in the programs were not adversely impacting market interest rates. This result is potentially good news for the Fed since it indicates that reductions in the supply of funds have not been a negative shock to the market.

Conclusion

The economic and financial crisis has caused large reductions in asset prices, in new issuances of primary securities and affected a wide variety of markets and institutions. The magnitude of these effects appears to be at variance with the relatively small losses that occurred in the subprime mortgage markets. In order to understand this amplification, we survey financial amplification mechanisms, focusing on balance sheet and adverse selection channels. We then discuss and interpret the Fed's actions during the crisis in terms of this literature. We show that the Fed's early stage liquidity programs were mainly designed to dampen down the balance sheet amplification arising from the positive feedback between financial constraints and asset prices. By comparison, the Fed's later stage crisis programs also take into account the adverse selection

amplification that operates via increases in credit risk and the externality imposed by risky borrowers on safe ones.

We examine how changes in the Fed's supply of liquidity (i.e. the amount of funds outstanding at the TAF and swap facilities) are associated with interest rate spreads, after controlling for credit risk and short-term funding conditions. We find that an increase in the supply of funds by the Fed is associated with a reduction in the Libor-OIS spread early in the crisis. During more recent periods, the Fed has been gradually withdrawing funds from these programs. We find that the reduced supply of funds by the Fed have had no significant impact on interest rate spreads in the most recent period. These results indicate that the potential withdrawal of liquidity by the Fed may not have an adverse impact on market prices.

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