Asani Sarkar and Jeffrey Shrader

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

1. Introduction

One of the primary questions associated with the recent financial crisis is how losses on subprime mortgage assets of approximately $300 billion[1] led to rapid and deep declines in the value of a wide range of other financial assets and, increasingly, real economic output. The disproportionate amount of total losses compared with 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 systemwide downturn. A further question is why subprime mortgage-backed securities (MBS) in particular, rather than any other asset, led to the downturn. Identifying key factors leading to the crisis, Blanchard (2009) cites the interaction between general market conditions, such as high leverage, underpricing of risk, and high interconnectedness, and certain features of subprime MBS, such as opacity, as well as investors' belief in ever-rising housing prices.[2]

In this paper, we examine how the conditions identified by Blanchard and other researchers led to widespread losses in financial markets. Our study focuses on two financial amplification mechanisms of relevance to the crisis: balance-sheet amplifiers and adverse-selection amplifiers.[3] We also interpret the actions of the Federal Reserve in the context of the literature on financial amplification mechanisms as well as provide new empirical evidence on the effectiveness of the Fed's liquidity supply during the crisis.

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 Long-Term Capital Management (LTCM) crisis of 1998 (Gromb and Vayanos 2002), and the current crisis (Bernanke 2009). Indeed, the Bank of England incorporates this mechanism into its quantitative Risk

[1] See the International Monetary Fund's "Global Financial Stability Report," April 2008.

[2] Acharya and Richardson (2009), Adrian and Shin (forthcoming), Brunnermeier (2009), and Gorton (2008), among others, also describe the genesis of the crisis and provide explanations for how it was propagated.

[3] For our discussion, a financial amplification mechanism represents the process whereby an initial shock occurring within the financial sector triggers substantially larger shocks elsewhere in the sector and in the real economy. A number of other mechanisms have been proposed in the literature. Examples are the maturity mismatch between assets and liabilities (Diamond and Dybvig 1983), Knightian uncertainty (Krishnamurthy forthcoming; Pritsker 2010), and interdependency from credit chains, whereby firms simultaneously borrow and lend (Kiyotaki and Moore 1997b).

Asani Sarkar is a research officer at the Federal Reserve Bank of New York; Jeffrey Shrader is a former assistant economist at the Bank.
asani.sarkar@ny.frb.org

The authors thank Viral Acharya, Mark Flannery, Gary Gorton, Arvind Krishnamurthy, and Lasse Pedersen for comments. The views expressed are those of the authors and do not necessarily reflect the position of the Federal Reserve Bank of New York or the Federal Reserve System.

Assessment Model for Systemic Institutions, or RAMSI (Aikman et al. 2009). In all of these cases, the initial trigger was relatively small in magnitude and local (for example, the Russian default in 1998 and news associated with mergers and acquisitions in 1987), but the crisis spread rapidly and globally to other markets. The amplification underlying these events is understood to operate as follows: an initial shock tightens funding constraints, causing the 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 reduce net worth, such as higher margins, lower collateral value, 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).

Central banks appear well placed to mitigate funding constraints as lenders of last resort (LOLRs). Since banks typically fund long-term assets with short-term money, a loss of confidence would force them to engage in asset "fire sales." By providing a liquidity backstop, central banks work to avoid potential fire sales. Bernanke (2009) describes the stages of the Federal Reserve's responses to the current crisis. The first-stage programs—the Term Auction Facility (TAF), central bank liquidity swaps, the Term Securities Lending Facility (TSLF), and the Primary Dealer Credit Facility (PDCF), all introduced between December 2007 and March 2008 (see exhibit)—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 Federal Reserve's first-stage liquidity programs and discuss available evidence on their effectiveness. The evidence is consistent with the view that the Fed mitigated funding stresses by charging lower effective rates on collateralized funds compared with rates in the private market. The Fed was able to take such action because, as a patient investor, it required a lower liquidity risk premium than private lenders did.

Next, we focus on the adverse-selection mechanism, which differs from the balance-sheet mechanism in terms of the role played by credit risk. The balance-sheet mechanism focuses on "collateralizable" net worth (Bernanke and Gertler 1989) and secured financing. Here, 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 is also a potentially important amplifier in crisis periods. Indeed, as the crisis evolved, 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 in the later stages of a crisis. We provide a brief survey of the literature that focuses mainly on those effects and their explicit policy implications, particularly for the current crisis. The literature finds that when borrowers have private information about their own asset values, private funding markets may break down, as safe borrowers exit the markets and lenders, faced with an adverse selection of risky borrowers, reduce their lending. The market failure provides a role for liquidity supply by central banks. However, the literature is also skeptical of the efficacy of such intervention in the face of asymmetric information.

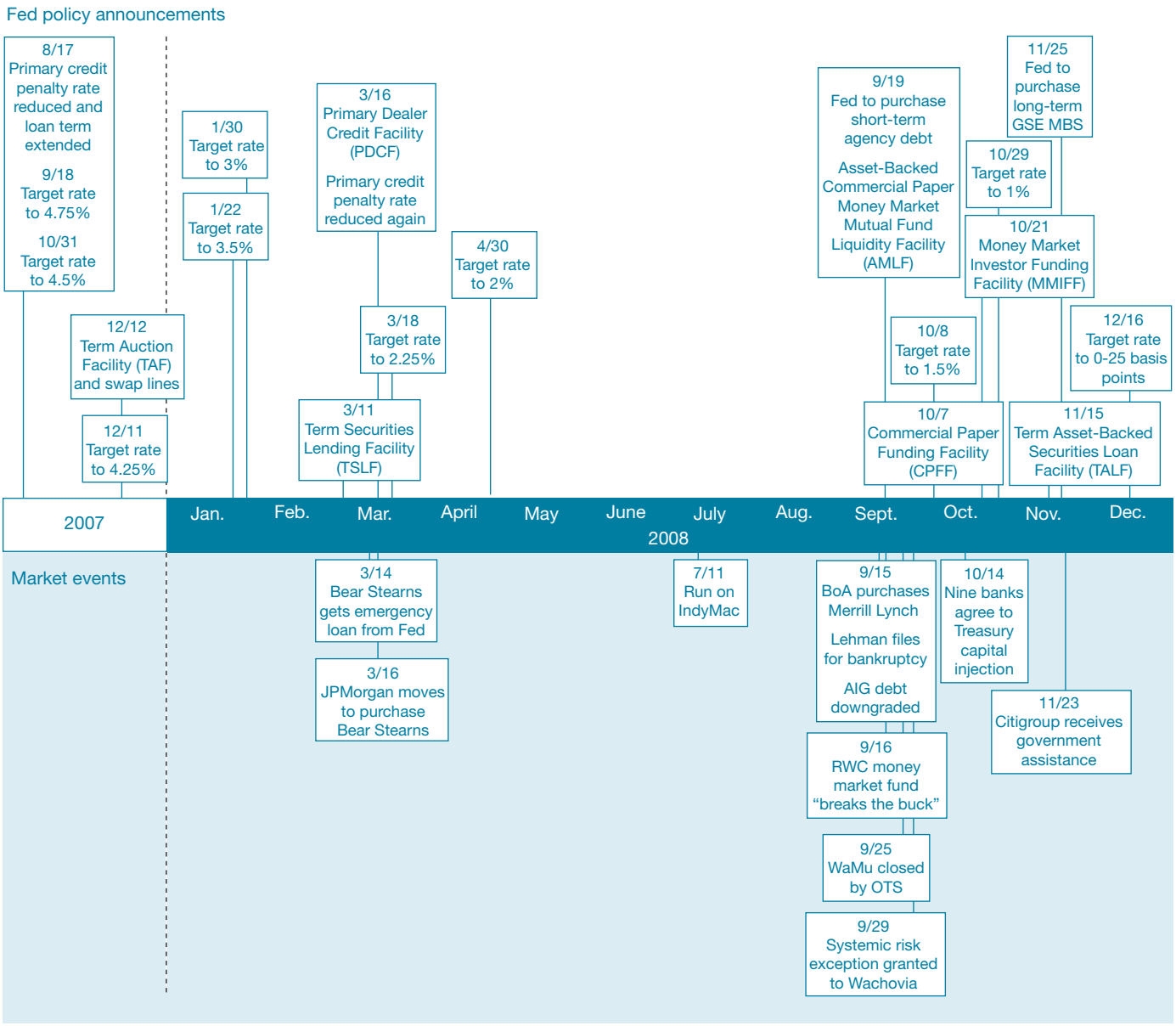
The Federal Reserve's crisis interventions evolved along with the changing nature of the crisis. The second-stage programs—the Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility (AMLF), the Commercial Paper Funding Facility (CPFF), the Money Market Investor Funding Facility (MMIFF), and the Term Asset-Backed Securities Loan Facility (TALF), all rolled out starting in September 2008 (see exhibit)—went beyond providing liquidity and addressed the funding needs of borrowers in selected credit markets. With these facilities, the Fed accepted a certain amount of credit risk, which it managed through the imposition of haircuts on the collateral given to it. The increased credit risk that the Fed accepted is attributable to the longer maturity of the loans (up to five years for TALF loans, for example), the nonrecourse nature of the loans in the case of the AMLF and TALF, and the broader set of counterparties (any U.S. company with eligible collateral can borrow at the TALF, for instance). Given the relatively late date of the introduction of these programs, examination of the programs and their effectiveness remains at an early stage.

Our study concludes by providing fresh evidence on the effect of changes in the Federal Reserve's supply of liquidity on changes in the three-month spread between the London interbank offered rate and the overnight indexed swap rate, better known as the Libor-OIS spread.[5] In contrast to previous work that focuses on announcement date effects, our paper examines changes in the amount outstanding of funds supplied by the Fed through the TAF and the 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 and decreasing supplies of funds by the Fed, and find that increases tend to reduce interest rates during

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

[5] Libor is a benchmark unsecured interbank interest rate published by the British Bankers' Association; OIS represents the expected average of the overnight fed funds rate over the term of the loan. The spread is widely used to measure interbank market stress.

Market Events and Federal Reserve Actions
December 2007-December 2008



periods of high funding liquidity risk. Surprisingly, decreases in the supply of funds also appear to be associated with lower spreads. Moreover, the impact of the funds supply on the spread has diminished over time, a result that is helpful in evaluating the impact of the Fed's potential future exit from its liquidity programs.

2. The Balance-Sheet Amplification Mechanism

The literature on balance-sheet mechanisms focuses on the principal agent problem between borrowers and lenders that arises from delegated investment. Households invest in hedge funds and mutual funds that invest in securities; these funds may in turn invest with more specialized investors with expertise in sophisticated trading strategies.[6] 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 the intermediary's balance-sheet conditions.

The balance-sheet amplification channel involves a positive feedback between funding constraints and changes in the asset values or cash flow of intermediaries. An early example is provided in 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 in which borrowers have better information about project quality than potential lenders do.[7] 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 attributable to countercyclical agency costs.

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

The generic balance-sheet constraint for time t can be expressed (following Krishnamurthy [forthcoming]) 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).[8] In other 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), in which 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:

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

Or, rewriting,

$$(1 - \gamma) P_t \theta_t \leq w_t. \tag{3}$$

Here, γ can be viewed as the "haircut" on the collateral. If we write $m = (1 - \gamma)P$, then equations 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 have 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 asset, and the magnitude of this loss is large because of leverage. The subsequent reduction in borrowing capacity leads to further rounds of decreased investments, asset prices, and borrower net worth.

While Bernanke and Gertler (1989) and Kiyotaki and Moore (1997a) are concerned with "collateralizable" net worth, they acknowledge but do not consider 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. However, they also 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 the difference between the transaction 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, such as the stock market crash of 1987 and the LTCM crisis of 1998.

Shleifer and Vishny (1997) examine the effect of intertemporal wealth constraints on the incentives of arbitrageurs to eliminate mispricings between two securities with identical cash flows. They consider the agency relationship

[6] For example, the "Fund of Funds" strategy is used by hedge funds that invest in other hedge funds.

[7] 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 a return for free.

[8] Margin constraints are 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.

between arbitrageurs with specialized market knowledge, such as hedge funds, and the investors who fund them, such as wealthy individuals, banks, and endowments. If investors chase returns, they are likely to withdraw capital from arbitrageurs when prices are falling. In turn, arbitrageurs lacking capital 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. Thus, arbitrage activity benefits all investors. It is assumed that arbitrageurs must have separate margin accounts for the two assets (that is, there is no cross-margining).[9] This implies that arbitrageur positions are wealth constrained. Gromb and Vayanos show that if changes in arbitrageur wealth are insufficient to cover variations in both margin accounts, arbitrageurs 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 capital gain from the arbitrage position is expected to be risky.[10] 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. By comparison, Brunnermeier and Pedersen (2009) derive a *margin spiral,* in which lower asset prices reduce arbitrageur net worth through 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 interdependent.

Brunnermeier and Pedersen 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. Financiers can reset margins every period, 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.[11] A funding shock to speculators lowers market liquidity and results in higher margins, which cause 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.[12] Thus, amplification works through fund flows and liquidity risk. The fact that inefficiencies can arise in the absence of credit risk suggests the positive role of central banks in alleviating funding and capital constraints during periods of crisis.

3. The Balance-Sheet Amplification Mechanism: Implications for Central Banks

The welfare analysis of Gromb and Vayanos (2002) shows that arbitrageurs may not take on an optimal level of risk, in part because they fail to internalize the effect on prices of changing their positions.[13] For example, arbitrageurs may underinvest in an arbitrage opportunity because they do not consider the possibility 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 in an arbitrageur's positions on other arbitrageurs.

[9] 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.

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

[11] This occurs if financiers are unsure if price changes are attributable to news shocks or liquidity shocks, and if volatility is time varying. Under these conditions, liquidity shocks lead to higher volatility, which increases financiers' expectations of future volatility; this in turn leads to higher margins. In contrast, if financiers know for sure that price changes are linked 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.

[12] This is explicit in Kiyotaki and Moore (1997a). Bernanke and Gertler (1989) explain that their model is about "collateralizable" net worth. The models of Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) rule out default because margin accounts must be fully collateralized.

[13] An important reason why arbitrageur position changes are "Pareto-improving"—that is, they make some people better off without making anyone worse off—is that price changes result in wealth redistributions, and market segmentation implies that agents' marginal rates of substitution differ (as shown by Geanakoplos and Polemarchakis [1986] in a general, incomplete market setting). Arbitrageurs prefer to receive more wealth earlier while other investors prefer to receive wealth later; this creates the potential for Pareto-improving wealth redistributions across time and states.

An implication of Gromb and Vayanos is that regulatory intervention may affect arbitrageurs' financial constraints by reducing their capital and margin requirements or by providing financing to those institutions that provide capital to arbitrageurs.[14] Since the ex ante choice of leverage may be suboptimal, 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 (because of 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 (financial firms such as brokers, banks, and clearinghouses). Further, such transfers need not be direct, rather, they could be channeled through financial intermediaries under the assumptions that the latter can identify legitimate borrowers and that 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 a central bank is effective at distinguishing news shocks and liquidity shocks and it conveys this distinction to financiers, the financiers 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 simply by stating its intention to do so. If the statement is credible, financiers may loosen margin requirements, because their worst-case scenarios have a lower probability of occurring.[15]

[14] When regulators have limited control over financial constraints, they may prefer to tighten them in some cases to reduce overinvestment (for example, by limiting entry into the arbitrage industry). Overinvestment occurs if arbitrageurs are initially fully invested in the arbitrage opportunity. If demand by other investors increases, the price discrepancy widens and arbitrageurs suffer capital losses on their current positions. If arbitrageurs reduce their positions, they limit losses and can provide liquidity in future periods by trading more aggressively, a practice that mitigates the price wedge.

[15] Allen, Carletti, and Gale (2009) provide another rationale for central bank intervention. When markets are incomplete, the authors show that the price of the long-lived asset may exhibit excessive volatility. By using open market operations appropriately to set 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 address systemic liquidity crises.

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

We turn to an assessment of the Federal Reserve's ex post interventions during the financial crisis, viewed in the context of the balance-sheet literature. From equations 1 and 3, we observe that a regulator has three types of instruments at its disposal:

- reducing m, the required margins on new funds;
- increasing γ, the value of pledgable assets;
- increasing w, the equity capital.

We 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 (2010) argue that, when there is generalized market failure, it may not make sense to provide liquidity at a penalty rate over the market rate because no institution benefits relative to others. The authors 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 in which a market price cannot be found."

Normally, the Fed provides reserves to a small number of primary dealers that distribute the funds to banks via interbank markets; in turn, banks lend to ultimate borrowers. When the markets are 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 the banks were reluctant, perhaps in part because of the "stigma" associated with such borrowing.[16]

Responding to these concerns, the Fed introduced a number of programs (the aforementioned stage-one group) between December 2007 and March 2008 designed to provide short-term liquidity to sound financial institutions.[17] In the context of the balance-sheet literature, the programs can be viewed as easing balance-sheet constraints and thereby breaking the illiquidity spiral. An example is the TSLF, which allows dealers to exchange illiquid securities (say, MBS) for liquid Treasury securities that the dealers can subsequently use as collateral to

[16] For example, Furfine (2003) presents evidence consistent with potential borrowers staying away from the discount window, perhaps out of concern that such borrowing would be viewed as a sign of higher credit risk. Armantier et al. (2010) provide evidence that a discount window stigma existed throughout the financial crisis.

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

borrow funds. The dealer pays a smaller haircut (say, *H_Treasury*) when borrowing against liquid Treasuries than what it pays (say, *H_Illiquid*) when borrowing against illiquid securities. Of course, the TSLF also charges a haircut (say, *H_TSLF*). However, as long as *H_TSLF* < (*H_Illiquid* - *H_Treasury*), the facility lowers the dealer's net funding costs. Thus, the TSLF may be viewed as increasing γ in equation 3.

Other stage-one programs may be viewed as breaking the margin spiral (reducing *m* in equation 1). For example, the TAF auctioned credit to eligible depository institutions for a term of twenty-eight days initially and up to eighty-four days by August 2008. A similar program, the PDCF, issued credit to primary dealers. The international counterpart to TAF is bilateral currency swap arrangements with foreign central banks, which allow the banks to provide dollars to institutions in their own jurisdictions. These programs may bring down *m* in two ways: They may provide financing when private financing is simply unavailable, or when private financing is available only at more expensive terms.

How effective were these programs in reaching their objectives? To answer this question, we examine one liquidity risk proxy: the spread between overnight repo rates on MBS and Treasury securities.[18] Because 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 became *relatively* illiquid, leading to an increase in the spread between agency MBS and Treasury repos.[19] 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 under duress. For these reasons, the MBS-Treasury repo spread provides a good proxy for funding illiquidity in the economy, not just in the secured financing markets.

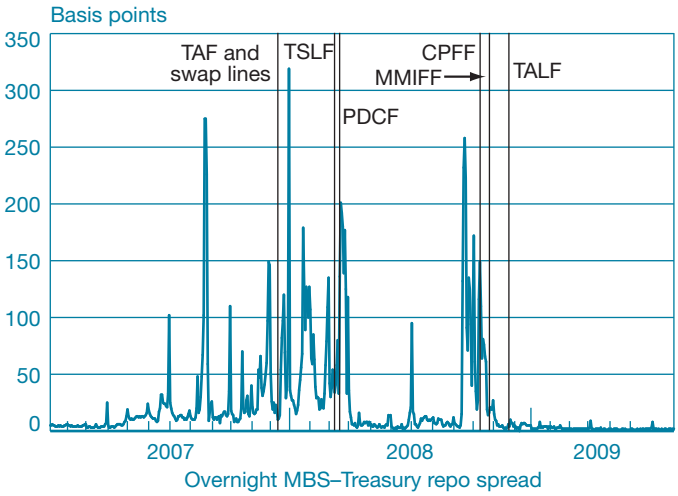
The source for the MBS-Treasury spread data is the Federal Reserve Bank of New York's primary dealer survey. The Trading Desk at the New York Fed collects information each morning from dealers on the average overnight general collateral repo rate at which each dealer has financed its positions in Treasury 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.

[18] Overnight repo rates on MBS are general collateral repo rates that reference nonspecific 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.

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

Chart 1

Liquidity Risk during the Financial Crisis



Sources: Federal Reserve Bank of New York; Haver Analytics.

Notes: MBS is mortgage-backed securities. Full names of the liquidity facilities appear in the exhibit on page 57.

Providing evidence on the effectiveness of the TSLF and PDCF programs, the spread between overnight agency MBS repo rates and Treasury collateral repo rates decreased after the TSLF program was implemented (Chart 1). 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.[20] Since the overnight repo spread may be attributable to the reduced collateral value (from lower market liquidity) of MBS relative to Treasuries, or to the increased collateral value of Treasuries (from higher market liquidity) relative to MBS, the reduction in the spread suggests an increase in γ.

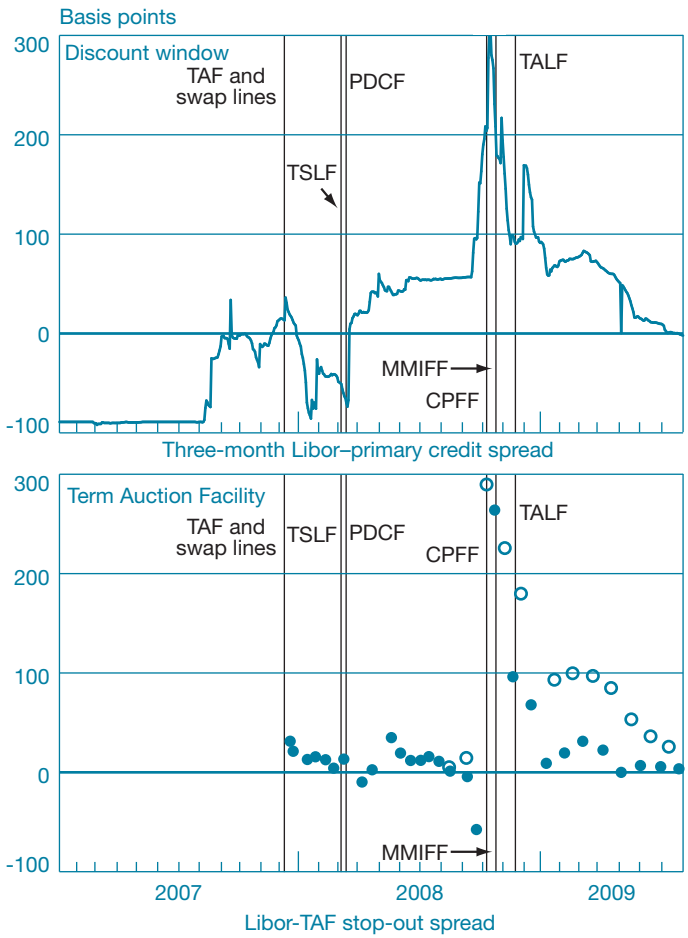
The top panel of Chart 2 shows the difference between the Libor, which is taken to be the benchmark borrowing rate in the private markets, and the discount window borrowing rate (the primary credit rate).[21] The discount window rate was

[20] Treasury securities are widely used as collateral for secured funding, so improved liquidity for Treasuries is likely to have a beneficial effect on secured funding rates in general. In addition, Fleming, Hrung, and Keane (2009) observe 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" (also see Fleming and Garbade [2004, 2005]).

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

Chart 2

Cost of Borrowing from the Federal Reserve Relative to the Market



Sources: Federal Reserve Bank of New York; Haver Analytics; British Bankers' Association; Bloomberg.

Notes: Libor is the London interbank offered rate. Solid circles represent the one-month Libor–twenty-eight-day TAF stop-out spread; open circles represent the three-month Libor–eighty-four-day TAF stop-out spread. For twenty-eight-day TAF auctions, the Libor-TAF spread is calculated as the spread between the one-month Libor and the twenty-eight-day TAF; for eighty-four-day TAF auctions, the spread is calculated as the spread between the three-month Libor and the eighty-four-day TAF. Full names of the liquidity facilities appear in the exhibit on page 57.

initially above the Libor, a development that partly explains banks' reluctance to use the window early in the crisis. The bottom panel of the chart illustrates the difference between the Libor and stop-out rates in the twenty-eight- and eighty-four-day TAF auctions. It shows that the 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.[22]

The Federal Reserve's success in easing funding constraints during the crisis likely had a beneficial effect on the real economy, via the channels suggested in Bernanke and Gertler (1989) and Kiyotaki and Moore (1997a). Del Negro et al. (2009), who extend the model of Kiyotaki and Moore (2008), study the impact of a large shock of the order of magnitude observed in the 2008 financial crisis. Their model simulations suggest that the Fed's policy interventions in 2008-09 prevented a repeat of the Great Depression.

5. The Adverse-Selection Amplification Mechanism: Implications for Central Banks

The Federal Reserve's first-stage liquidity programs exposed it to minimal credit risk. The Fed's loans to banks and primary dealers through the various facilities are overcollateralized and made with recourse to the borrowing firm.[23] In the case of the currency swap lines, the foreign central 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 evolved, 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 central bank to the economy.[24] As these intermediaries themselves became impaired, they were less willing to lend. In addition, certain credit markets, such as commercial paper, were 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 our

[22] McAndrews, Sarkar, and Wang (2008) study the effect of the TAF on the Libor-OIS spread. McAndrews (2009) and Coffey, Hrung, and Sarkar (2009) analyze the effect of swap lines: the former on the Libor–fed funds spread, the latter on deviations from covered interest rate parity. Cetorelli and Goldberg (2009) examine the effect of liquidity programs on the internal capital markets of global banks.

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

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

review of balance-sheet amplifiers, we focus here on the role of credit risk and the distribution of credit risk across borrowers. The papers surveyed in this discussion find a role for central bank intervention when adverse-selection problems lead to market breakdowns. However, they also raise concerns that central bank liquidity provision might crowd out private market liquidity.

Heider, Hoerova, and Holthausen (2009) build a model of the effect of counterparty risk on unsecured interbank markets with asymmetric information.[25] Banks need liquidity, as customers may withdraw deposits on demand (as in Diamond and Dybvig [1983]). The interbank markets distribute funding from banks with excess reserve balances to those with reserve shortages. Counterparty risk exists because 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 markets depending on the level and distribution of counterparty risk. Because 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 with the opportunity cost of funds, so the interbank markets perform smoothly with low interest rates. If, however, the risk premium is too high, safe borrowers exit the interbank markets. Consequently, in this "worst" regime, lenders face an adverse selection of risky borrowers and the interest rate is high. In this regime, both the level and the dispersion of credit risk are high;[26] as a result, the interbank markets stop functioning. Either lenders find it unprofitable to lend (even at high interest rates) and thus hoard funds,[27] or risky borrowers find the interest rate too high and exit.

What are the implications of this model for central bank liquidity supply? [28] Suppose credit risk increases unexpectedly and lenders face an adverse selection of borrowers (but the 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 accept. As in Flannery (1996), this rate is discounted relative to the market rate, and the central bank's 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 central bank liquidity crowds out private liquidity.[29] Their model features two types of investors: short-run investors, who invest in valuable risky projects that typically mature early, and long-run investors, who invest in higher return long-term assets. The ex ante efficient solution is for short-run investors to sell risky assets to long-run investors (to obtain "outside" liquidity) and for trading not to occur too quickly. However, short-run investors have private information about the assets. If investors are concerned about adverse-selection problems that may undermine secondary markets in the future, 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 the supply. If it delays liquidity provision, it crowds out outside liquidity and undermines the incentives of short-run investors to obtain outside liquidity by selling assets for cash. However, if the central bank acts quickly, its liquidity can complement private market liquidity. In this case, the central bank plays the role of market maker of last resort by inducing short-run investors to obtain liquidity through asset sales.

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

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

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

[28] 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 (central bank) 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 to monitor banks and provide them with liquidity during crises in order to prevent inefficient panics. Acharya, Gromb, and Yorulmazer (2008) examine how the strategic power of an interbank 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.

[29] 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 because households face costs associated with 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 through 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 that lack access to markets. The financial system is efficient as long as markets are complete.

6. 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, came in two varieties (see exhibit). Continuing its LOLR role, the Federal Reserve provided a liquidity backstop to money market mutual funds and to commercial paper borrowers. The Fed developed a facility to finance bank purchases of high-grade asset-backed commercial paper from money market mutual funds, which helped the funds to meet redemption demands without having to sell assets at distress prices. Through another facility, the Fed bought high-quality (A1-P1) commercial paper at a term of three months, which reduced the risk of commercial paper borrowers being unable to roll over maturing issues.

The second type of Federal Reserve programs went beyond providing liquidity to address the funding needs of borrowers in selected asset-backed markets. The TALF, representing a joint effort with the U.S. Treasury, provides three- or five-year term loans to investors against (mostly) new issuances of AAA-rated securities. With the Treasury providing funding, the facility allows the Fed to accept a certain amount of credit risk. The Fed manages the credit risk through the imposition 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, it offers funding at different rates for various asset classes (as 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 credit risk, a concern raised by Goodfriend and King (1988) and Heider, Hoerova, and Holthausen (2009).

Given the relative newness of these programs, rigorous empirical evidence on their effectiveness is scarce. An exception is Ashcraft, Garleanu, and Pedersen (2009), who report the results of a survey of financial institutions on how the institutions' bid prices for securities depend on Federal Reserve financing. The Fed, by offering loans at lower margins than the market, effectively lowers the required return for holding securities put to the 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 of lower margins on asset prices.

7. Evolution of Credit and Liquidity Risk during the Crisis

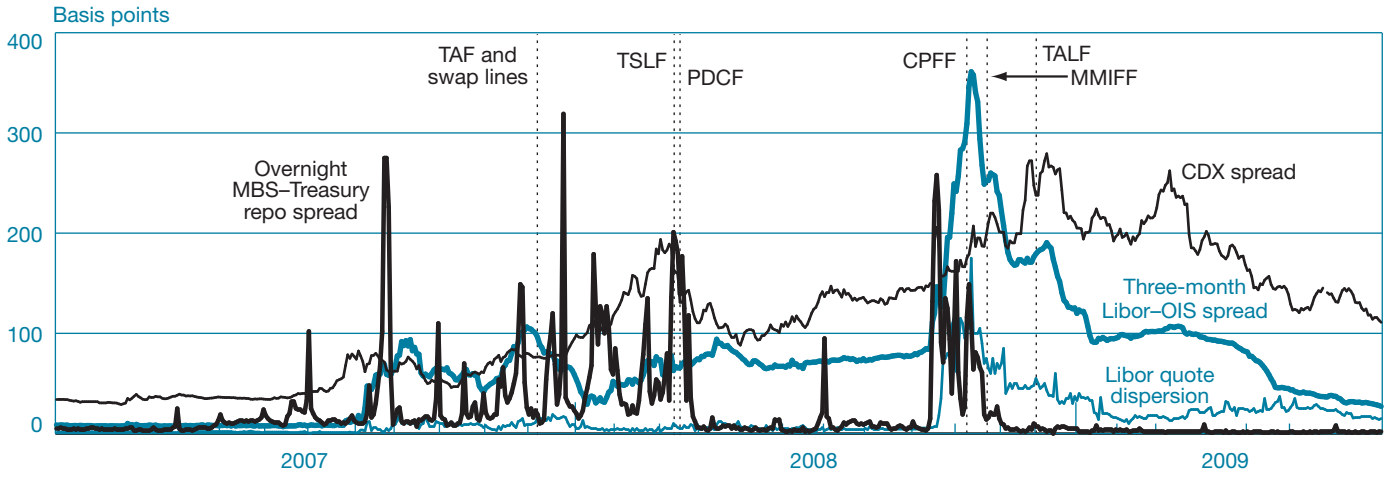
As the crisis progressed, the relative importance of the balance-sheet and adverse-selection mechanisms likely changed. This evolution is implicit in the timing of the Fed's responses. In particular, the Fed's stage-one programs emphasized the provision of liquidity to solvent institutions, suggesting that at this early point in the crisis the Fed viewed a lack of 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 on 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 amplification mechanisms over time.

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

The Libor panel dispersion, provided by the British Bankers' Association via Bloomberg, is defined as the difference between the maximum and minimum three-month quote of the sixteen Libor panel banks each day; it proxies for uncertainty about counterparty credit risk. The quote dispersion shows the extent to which some Libor panel banks report greater borrowing costs, an indicator of higher counterparty risk compared with the typical Libor panel bank. Our uncertainty measure is consistent with those proposed in Heider, Hoerova, Holthausen (2009) and Pritsker (2010), that is, 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.

Balance-sheet effects operate according to illiquidity and margin conditions. To measure liquidity risk, we use the spread overnight MBS and Treasury general collateral repo rates. As discussed in Section 4, the spread between these two rates should primarily reflect the relative illiquidity of MBS relative

Chart 3
Risk Evolution during the Crisis



Sources: Federal Reserve Bank of New York; Haver Analytics, Markit; British Bankers' Association.

Notes: MBS is mortgage-backed securities; Libor is the London interbank offered rate. The overnight MBS–Treasury repo spread is the liquidity risk proxy; the CDX spread and the Libor quote dispersion are the credit risk proxies. Full names of the liquidity facilities appear in the exhibit on page 57.

to Treasuries. The credit risk component of these two rates is minimal because of the secured nature of the transaction, the short duration of the loan, and haircuts that are generally set in advance. In contrast, the daily repo rate on a given day reflects supply and demand pressures in the market. During the financial crisis, there was a rush to buy Treasuries, which increased the demand for these securities. The greater demand likely lowered the risk of a repo buyer being unable to sell the Treasuries in the event of counterparty default. Impairment in the MBS market, however, meant that the same was not true for buyers accepting MBS securities as collateral. Therefore, the differences in these two rates reflect the ability of buyers to quickly and easily sell the collateral from their repo transactions—in other words, the two securities are relatively liquid. We compare these series to the three-month Libor-OIS spread, which contains credit and noncredit risk premia. Arbitrage should normally ensure that the spread is close to zero, but the spread has widened dramatically during the crisis (Chart 2).[30] 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 three months. We use t+1 Libor rates because the rate is fixed each morning at 11:00 a.m. London time while the OIS rate is determined at the end of the business day, U.S. Eastern time.

Chart 3 illustrates the evolution of liquidity risk (the MBS-Treasury repo spread) and credit risk (the CDX IG index and Libor quote dispersion) during the crisis, along with the Libor-OIS spread. All values are in basis points. The evolution of risk proxies is consistent with the view that, at the beginning of the crisis, liquidity risk was relatively more important than credit risk, but 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 longer.

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 spread more formally in the next section.

[30] The arbitrage works as follows: loan $X for, say, three months, 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).

8. Effectiveness of the Fed's Liquidity Supply: Methodology

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

We interpret the TAF and swap programs as primarily intending to decrease liquidity risk. Because the Libor-OIS spread contains credit and noncredit 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 the amount of funds outstanding, which are the net effect of changes in the Fed's supply of funds and repayment of funds by participating banks. During the first ten months of TAF operation, the Fed raised the maximum amount offered at auction four times, introduced longer term auctions, and increased the frequency of auctions. The swap facility underwent similar changes, such as increases in size and adjustments in frequency. These changes worked mainly to increase the size of the programs; more recently, the Fed has been reducing their size.

Our maintained assumption is that changes in the TAF and in the swap amount outstanding are exogenous. Before October 2008, the Fed and other central banks determined the maximum offering amount for the TAF and the 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, uncertainty remained about whether the auctions would be fully subscribed; therefore, changes in the amount outstanding were not fully anticipated by banks. We calculate changes in the amount outstanding to occur on the day of disclosure rather than on the date of funds disbursement (generally two days later) to maximize the "news" content of 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 any quantity of funds. 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 to be greater since October 2008. To mitigate this concern, we include the Treasury-MBS general collateral repo spread to help control for changes in bank demand for TAF and swap loans.

McAndrews, Sarkar, and Wang (2008) decompose the Libor-OIS spread into its credit risk and non–credit-risk components for the January 2007-April 2008 period. They find that the non–credit-risk component was the major part of the spread in 2007. The credit risk component was high and volatile in 2008. However, because the 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, the authors find that the Fed's announcements of new supplies of TAF funds significantly reduced the Libor-OIS spread during their sample period.

Our analysis differs from that study's approach in four primary respects. First, we use changes in the 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 supply changes, unlike the auction date variables used by McAndrews, Sarkar, and Wang, which are binary. Second, our examination of a longer time series enables us to analyze recent decreases in the size of these facilities, potentially allowing us to draw implications for the Fed's exit strategies. Third, we look at the TAF and swap facilities simultaneously, a natural approach because of the facilities' high degree of similarity. Both are intended to provide dollar funding to a broad range of counterparties, both were introduced at the same time and relatively early in the crisis, and both correspond closely in terms of the timing, terms, and magnitude of auctions. Finally, we employ an expanded set of covariates to control for credit and liquidity risk.

We examine interactions between binary variables over four periods and the TAF and swap amounts outstanding to allow for changes in the importance of liquidity risk over time.[31] The periods are chosen to correspond to the turning points of the crisis and to encompass TAF and swap auctions that occurred around these 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.

[31] The effect of risk variables on the Libor-OIS spread could also change over time. Unreported results from regressions allowing the risk variable coefficients to vary over different crisis periods indicate no qualitative changes to our estimates for the amounts outstanding of the TAF and swap variables.

Table 1

Variables Used in Regressions

Variable	Description	Unit
Three-month Libor-OIS spread on date *t*	Three-month Libor on date *t*+1 minus three-month OIS rate on date *t*	Basis points
TAF outstanding	Outstanding value of TAF funds on award announcement date	Billions of U.S. dollars
Non-negative component of TAF outstanding	Equal to the maximum of TAF outstanding and 0	Billions of U.S. dollars
Non-positive component of TAF outstanding	Minimum of 0 and TAF outstanding	Billions of U.S. dollars
Swap outstanding	Outstanding value of all swap lines on award announcement date	Billions of U.S. dollars
Non-negative component of swap outstanding	Maximum of swap outstanding and 0	Billions of U.S. dollars
Non-positive component of swap outstanding	Minimum of 0 and swap outstanding	Billions of U.S. dollars
Period 1	Binary variable equal to 1 for dates between August 1, 2007, and March 9, 2008; 0 otherwise	—
Period 2	Binary variable equal to 1 for dates between March 10, 2008, and September 9, 2008; 0 otherwise	—
Period 3	Binary variable equal to 1 for dates between September 10, 2008, and December 31, 2008; 0 otherwise	—
Period 4	Binary variable equal to 1 for dates between January 2, 2009, and July 31, 2009; 0 otherwise	—
CDX spread	CDX IG index	Basis points
Three-month Libor quote dispersion on date *t*	Difference between maximum and minimum quote of banks in three-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 Treasury general collateral repo rate	Basis points

Note: Libor is the London interbank offered rate; TAF is the Term Auction Facility; MBS is mortgage-backed securities.

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

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

The equation relates changes in the Libor-OIS spread to changes in the amounts 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). Because VIX has been found to be a significant determinant of asset prices in several markets, we use it to account for financial market risk broadly.[32] Finally, we control for banks' balance-sheet funding risk using the overnight MBS-Treasury repo spread ($\Delta MBS - TRSY\_REPO$). We use changes in variables to account for deterministic time-series effects, such as trends. All variables are summarized in Table 1. TAF auction results are from the Federal Reserve Board website; swap line results are from participating central bank websites.[33] VIX data are from Bloomberg.

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

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

[32] VIX has been shown to be a significant determinant of prices of foreign exchange (Brunnermeier, Nagel, and Pedersen 2008) and sovereign CDS (Longstaff et al. 2007).

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

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

The balance-sheet constraint is predicted to bind on the down side (when intermediaries are capital constrained) but not on the up side (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 them.

9. The Effectiveness of the Fed's Liquidity Supply: Results

Table 2 presents our results from estimating equation 4. The results indicate that the supply of funds from both the TAF and the swap line programs was associated with a reduction in the Libor-OIS spread during the early phase of the crisis (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 spread of 0.1 to 0.5 basis point during this period. This result is consistent with the operation of the balance-sheet amplification mechanism in the early stage of the crisis.

We find that in subsequent periods, the supply of TAF and swap funds is not a significant predictor of the interest rate spread. The sign of the TAF supply coefficient remains negative in Periods 2 and 3, but it is not significant.[34] In the next section, we show that this apparent lack of significance may be attributable to an averaging of the separate effects of increases and decreases in the supply of funds. The sign of the swap line coefficient is negative in Periods 1 and 3. Overall, considering

[33] http://www.federalreserve.gov/monetarypolicy/taf.htm
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

[34] The difference between the TAF coefficient in the early crisis period (Period 1) and Period 2 is not statistically significant, 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.

Table 2
Changes in Amounts Outstanding at Federal Reserve Facilities, and the Libor-OIS Spread
August 2007-July 2009

Dependent Variable: Change in Three-Month Libor-OIS Spread

Explanatory Variable	Coefficient
Change in TAF outstanding	
Period 1: August 1, 2007–March 9, 2008	-0.130***
	(0.037)
Period 2: March 10, 2008–September 9, 2008	-0.167
	(0.110)
Period 3: September 10, 2008–December 31, 2008	-0.031
	(0.036)
Period 4: January 2, 2009–July 31, 2009	0.009
	(0.018)
Change in swap outstanding	
Period 1: August 1, 2007–March 9, 2008	-0.481***
	(0.150)
Period 2: March 10, 2008–September 9, 2008	0.048
	(0.065)
Period 3: September 10, 2008–December 31, 2008	-0.047
	(0.064)
Period 4: January 2, 2009–July 31, 2009	0.019
	(0.016)
Credit risk	
Change in CDX spread	0.140***
	(0.042)
Change in three-month 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^2	0.17
Observations	607

Source: Authors' calculations, based on data from the British Bankers' Association, Haver Analytics, the Board of Governors of the Federal Reserve System, foreign central banks, the Federal Reserve Bank of New York, and Markit.

Notes: Newey-West standard errors (five lags) are in parentheses. The full sample is daily observations from January 3, 2007, to July 31, 2009. TAF is the Term Auction Facility. See Table 1 for a description of variables.
*** p<0.01.
** p<0.05.
* p<0.1.

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.[35] The overnight repo spread is also positively associated with the Libor-OIS spread during the crisis, but the estimate is only significant at the 10 percent level. As we discussed, the marginal significance of the repo spread might be explained by the Fed's action to reduce the spread through the PDCF and TSLF programs. Finally, changes in VIX are also significantly and positively associated with the Libor-OIS spread.[36]

Results from the regressions provide an indication of when the Fed might expect its liquidity facilities to help improve funding conditions. Comparing the coefficient estimates with the results in Chart 3, 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 during 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: to provide short-term funding to banks. As such, these facilities were not expected to have a direct effect on the credit risk of banks.

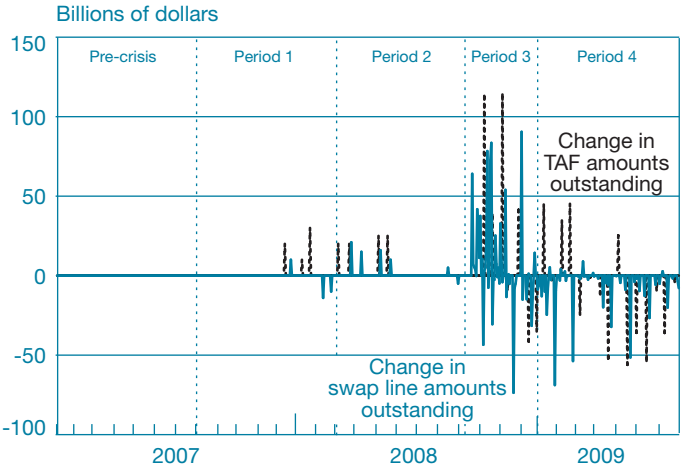
10. Asymmetric Market Responses to the Fed's Liquidity Supply

We next report estimates using TAF and swap outstanding variables decomposed into positive and negative changes. Chart 4 presents the time-series plots of the two main variables of interest: changes in TAF and swap amounts outstanding. Note that the TAF has experienced negative changes in amounts outstanding since Period 3, 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 with the total number of changes, is small in Periods 1 and 2, and rises to 40 percent in Period 3 and 80 percent in Period 4.

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

[36] We also considered the term premium, defined as the spread between the five- and two-year on-the-run Treasury yields, but this variable was not a significant predictor of the Libor-OIS spread.

Chart 4
Changes in Term Auction Facility (TAF) and Swap Line Amounts Outstanding



Sources: Federal Reserve Bank of New York; foreign central banks.

Note: Vertical lines correspond to the period divisions used in the estimations.

The results from estimation of the second regression are presented in Table 3. *Symmetric* responses of the Libor-OIS spread are indicated by negative changes to both increases and decreases in the amount outstanding—that is, 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 Stearns 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 the Fed's 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 swap amounts 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 the TAF amount outstanding. This asymmetry suggests that the lack of significance in the overall TAF coefficients during Periods 3 and 4 in Table 2 may be attributable 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 3

Positive and Negative Changes in Amounts Outstanding at Federal Reserve Facilities

August 2007-July 2009

Dependent Variable: Change in Three-Month Libor-OIS Spread	
Explanatory Variable	Coefficient
Positive changes in TAF outstanding	
Period 1: August 1, 2007–March 9, 2008	-0.093**
	(0.045)
Period 2: March 10, 2008–September 9, 2008	-0.033
	(0.078)
Period 3: September 10, 2008–December 31, 2008	-0.134***
	(0.020)
Period 4: January 2, 2009–July 31, 2009	-0.108**
	(0.045)
Negative changes in TAF outstanding	
Period 3: September 10, 2008–December 31, 2008	0.150***
	(0.016)
Period 4: January 2, 2009–July 31, 2009	0.034**
	(0.015)
Positive changes in swap outstanding	
Period 1: August 1, 2007–March 9, 2008	-0.957***
	(0.050)
Period 2: March 10, 2008–September 9, 2008	0.036
	(0.066)
Period 3: September 10, 2008–December 31, 2008	-0.084
	(0.083)
Period 4: January 2, 2009–July 31, 2009	0.204
	(0.161)
Negative changes in swap outstanding	
Period 1: August 1, 2007–March 9, 2008	-0.304***
	(0.036)
Period 2: March 10, 2008–September 9, 2008	-0.087*
	(0.050)
Period 3: September 10, 2008–December 31, 2008	0.063
	(0.045)
Period 4: January 2, 2009–July 31, 2009	0.021
	(0.015)
Constant	0.252
	(0.264)
Risk variables included?	Yes
Adjusted R^2	0.19
Observations	475

Source: Authors' calculations, based on data from the British Bankers' Association, Haver Analytics, the Board of Governors of the Federal Reserve System, foreign central banks, the Federal Reserve Bank of New York, and Markit.

Notes: Newey-West standard errors (five lags) are in parentheses. Negative changes in TAF outstanding did not occur until Period 2. The full sample is daily observations from January 3, 2007, to July 31, 2009. TAF is the Term Auction Facility. See Table 1 for a description of variables.

*** p<0.01.

** p<0.05.

* p<0.1.

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 the TAF and swap lines and no relationship for negative changes. We find, however, that declines in the TAF amount 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 amount outstanding during Period 3 occur in December 2008, when risk factors were already beginning to normalize. In Chart 3, one can see that by December 2008 liquidity risk had declined, as had the Libor quote dispersion, although the CDX index had remained elevated.

The results in Table 3 also shed light on the Fed's exit strategy from these programs. First, the decline 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. Chart 2 supports this view by showing that the spread between Libor and the Fed facilities has been steadily decreasing since early 2009. The view is further supported by the coefficient estimates on the negative changes in the TAF and swap amounts outstanding in 2009 (Table 3), indicating that the reductions in the programs were not adversely affecting market interest rates. This result represents a potentially positive sign for the market, as it indicates that reductions in the supply of funds by the Fed have not been a negative shock.

11. Conclusion

The financial crisis has led to large reductions in asset prices and in new issuances of primary securities while affecting a wide variety of markets and institutions. Yet the magnitude of these effects appears to be disproportionate to the relatively small losses that occurred in the subprime mortgage markets. To explain this seeming disparity, our paper surveys the literature on financial amplification mechanisms, focusing on the balance-sheet and adverse-selection channels. It then discusses and interprets the Federal Reserve's actions during the crisis in terms of the literature. We show that the Fed's early-stage liquidity programs were mainly designed to dampen the balance-sheet amplification arising from the positive feedback between financial constraints and asset prices. The Fed's later-stage crisis programs take into account the adverse-selection amplification that operates through increases in credit risk and the externality imposed by risky borrowers on safe ones.

We also examine how changes in the Fed's supply of liquidity (the amount of funds outstanding at the TAF and swap facilities) are associated with changes in interest rate spreads, after controlling for credit risk and short-term funding conditions. We find that an increase in the supply of funds 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 has had no significant impact on interest rate spreads in these periods. These results suggest that the potential withdrawal of liquidity by the Fed may not have an adverse effect on market prices.

References

Acharya, V., D. Gromb, and T. Yorulmazer. 2008. "Imperfect Competition in the Inter-Bank Market for Liquidity as a Rationale for Central Banking." Unpublished paper, London Business School.

Acharya, V., and M. Richardson, eds. 2009. Restoring Financial Stability: How to Repair a Failed System. John Wiley & Sons.

Adrian, T., C. R. Burke, and J. J. McAndrews. 2009. "The Federal Reserve's Primary Dealer Credit Facility." Federal Reserve Bank of New York Current Issues in Economics and Finance 15, no. 4 (August).

Adrian, T., and H. Shin. Forthcoming. "The Changing Nature of Financial Intermediation and the Financial Crisis of 2007-2009." Annual Review of Economics.

Aikman, D., P. Alessandri, B. Eklund, P. Gai, S. Kapadia, E. Martin, N. Mora, G. Sterne, and M. Willison. 2009. "Funding Liquidity Risk in a Quantitative Model of Systemic Stability." Bank of England Working Paper no. 372, June.

Allen, F., and E. Carletti. 2008. "The Role of Liquidity in Financial Crises." In Maintaining Stability in a Changing Financial System. Proceedings of the 2008 Jackson Hole Economic Symposium, Federal Reserve Bank of Kansas City, August 21-23.

Allen, F., E. Carletti, and D. Gale. 2009. "Interbank Market Liquidity and Central Bank Intervention." Journal of Monetary Economics 56, no. 5 (July): 639-52.

Allen, F., and D. Gale. 2004. "Financial Intermediaries and Markets." Econometrica 72, no. 4 (July): 1023-61.

Armantier, O., E. Ghysels, A. Sarkar, and J. Shrader. 2010. "Stigma in Financial Markets: Evidence from Liquidity Auctions and Discount Window Borrowing during the Crisis." Unpublished paper, Federal Reserve Bank of New York.

Armantier, O., S. Krieger, and J. McAndrews. 2008. "The Federal Reserve's Term Auction Facility." Federal Reserve Bank of New York Current Issues in Economics and Finance 14, no. 5 (July).

Ashcraft, A., N. Garleanu, and L. H. Pedersen. 2009. "Haircuts or Interest Rate Cuts: New Evidence on Monetary Policy." Unpublished paper, Federal Reserve Bank of New York, University of California at Berkeley, and New York University.

Bernanke, B. 2009. "The Crisis and the Policy Response." Stamp Lecture, London School of Economics, London, England, January 13.

Bernanke, B., and M. Gertler. 1989. "Agency Costs, Net Worth, and Business Fluctuations." American Economic Review 79, no. 1 (March): 14-31.

———. 1990. "Financial Fragility and Economic Performance." Quarterly Journal of Economics 105, no. 1 (February): 87-114.

Blanchard, O. 2009. "The Crisis: Basic Mechanisms and Appropriate Policies." International Monetary Fund Working Paper no. 09/80, April.

Bolton, P., T. Santos, and J. A. Scheinkman. 2009. "Inside and Outside Liquidity." NBER Working Paper no. 14867, April.

Brunnermeier, M. K. 2009. "Deciphering the Liquidity and Credit Crunch 2007-2008." Journal of Economic Perspectives 23, no. 1 (winter): 77-100.

Brunnermeier, M. K., S. Nagel, and L. H. Pedersen. 2008. "Carry Trades and Currency Crashes." In D. Acemoglu, K. Rogoff, and M. Woodford, eds., NBER Macroeconomics Annual 2008, 313-47. Chicago: University of Chicago Press.

Brunnermeier, M. K., and L. H. Pedersen. 2009. "Market Liquidity and Funding Liquidity." Review of Financial Studies 22, no. 6 (June): 2201-38.

Cecchetti, S. G., and P. Disyatat. 2010. "Central Bank Tools and Liquidity Shortages." Federal Reserve Bank of New York Economic Policy Review 16, no. 1 (August): 29-42.

Cetorelli, N., and L. Goldberg. 2009. "Following the Money in Global Banks: Internal Transfers during the Crisis." Unpublished paper, Federal Reserve Bank of New York.

Coffey, N., W. B. Hrung, and A. Sarkar. 2009. "Capital Constraints, Counterparty Risk, and Deviations from Covered Interest Rate Parity." Federal Reserve Bank of New York Staff Reports, no. 393, October.

Del Negro, M., G. Eggertsson, A. Ferrero, and N. Kiyotaki. 2009. "The Great Escape? A Quantitative Evaluation of the Fed's Non-Standard Policies." Unpublished paper, Federal Reserve Bank of New York.

References (Continued)

Diamond, D. W. 1997. "Liquidity, Banks, and Markets." Journal of Political Economy 105, no. 5 (October): 928-56.

Diamond, D. W., and P. H. Dybvig. 1983. "Bank Runs, Deposit Insurance, and Liquidity." Journal of Political Economy 91, no. 3 (June): 401-19.

Diamond, D. W., and R. G. Rajan. 2005. "Liquidity Shortages and Banking Crises." Journal of Finance 60, no. 2 (April): 615-47.

Fecht, F. 2004. "In the Stability of Different Financial Systems." Journal of the European Economic Association 2, no. 6 (December): 969-1014.

Flannery, M. J. 1996. "Financial Crises, Payment System Problems, and Discount Window Lending." Journal of Money, Credit, and Banking 28, no. 4, part 2 (November): 804-24.

Fleming, M. J., and K. D. Garbade. 2004. "Repurchase Agreements with Negative Interest Rates." Federal Reserve Bank of New York Current Issues in Economics and Finance 10, no. 5 (April).

———. 2005. "Explaining Settlement Fails." Federal Reserve Bank of New York Current Issues in Economics and Finance 11, no. 9 (September).

Fleming, M. J., W. B. Hrung, and F. H. Keane. 2009. "The Term Securities Lending Facility: Origin, Design, and Effects." Federal Reserve Bank of New York Current Issues in Economics and Finance 15, no. 2 (February).

Furfine, C. H. 2003. "Standing Facilities and Interbank Borrowing: Evidence from the Federal Reserve's New Discount Window." International Finance 6, no. 3 (winter): 329-47.

Geanakoplos, J., and H. M. Polemarchakis. 1986. "Existence, Regularity, and Constrained Suboptimality of Competitive Allocations when the Asset Market Is Incomplete." In W. P. Heller, R. M. Starr, and D. A. Starrett, eds., Uncertainty, Information, and Communication, vol. 3, 65-95. Cambridge University Press.

Goodfriend, M., and R. C. King. 1988. "Financial Deregulation, Monetary Policy, and Central Banking." In W. S. Haraf and R. M. Kushmeider, eds., Restructuring Banking and Financial Services in America. Washington, D.C.: American Enterprise Institute for Public Policy Research.

Gorton, G. B. 2008."The Panic of 2007." In Maintaining Stability in a Changing Financial System, 131-262. Proceedings of the Federal Reserve Bank of Kansas City's 2008 Jackson Hole Symposium. Available at http://www.kc.frb.org/publicat/sympos/2008/Gorton.03.12.09.pdf.

Gorton, G. B., and L. Huang. 2006. "Banking Panics and the Endogeneity of Central Banking." Journal of Monetary Economics 53, no. 7 (October): 1613-29.

Gorton, G. B., and A. Metrick. 2009. "Securitized Banking and the Run on the Repo." Yale University, International Center for Finance Working Paper no. 09-14, November.

Gromb, D., and D. Vayanos. 2002. "Equilibrium and Welfare in Markets with Financial Constrained Arbitrageurs." Journal of Financial Economics 66, nos. 2-3 (November-December): 361-407.

He, Z., and A. Krishnamurthy. 2008. "A Model of Capital and Crises." Unpublished paper, Northwestern University.

Heider, F., M. Hoerova, and C. Holthausen. 2009. "Liquidity Hoarding and Interbank Market Spreads: The Role of Counterparty Risk." European Central Bank Working Paper no. 1126, December.

Holmstrom, B., and J. Tirole. 1998. "Private and Public Supply of Liquidity." Journal of Political Economy 106, no. 1 (February): 1-40.

Hordahl, P., and M. R. King. 2008. "Developments in Repo Markets during the Financial Turmoil." BIS Quarterly Review, December: 37-53.

Kiyotaki, N., and J. Moore. 1997a. "Credit Cycles." Journal of Political Economy 105, no. 2 (April): 211-48.

———. 1997b. "Credit Chains." Unpublished paper, London School of Economics.

———. 2008. "Liquidity, Monetary Policy, and Business Cycles." Unpublished paper, Princeton University.

Krishnamurthy, A. Forthcoming. "Amplification Mechanisms in Liquidity Crises." American Economic Journal: Macroeconomics.

References (Continued)

Longstaff, F. A., J. Pan, L. H. Pedersen, and K. J. Singleton. 2007. "How Sovereign Is Sovereign Credit Risk?" NBER Working Paper no. 13658, December.

McAndrews, J. 2009. "Segmentation in the U.S. Dollar Money Markets during the Financial Crisis." Unpublished paper, Federal Reserve Bank of New York.

McAndrews, J., A. Sarkar, and Z. Wang. 2008. "The Effect of the Term Auction Facility on the London Inter-Bank Offered Rate." Federal Reserve Bank of New York Staff Reports, no. 335, July.

Pritsker, M. 2010. "Informational Easing: Improving Credit Conditions through the Release of Information." Federal Reserve Bank of New York Economic Policy Review 16, no. 1 (August): 77-87.

Rochet, J.-C., and X. Vives. 2004. "Coordination Failures and the Lender of Last Resort: Was Bagehot Right after All?" Journal of the European Economic Association 2, no. 6 (December): 1116-47.

Shleifer, A., and R. W. Vishny. 1997. "The Limits of Arbitrage." Journal of Finance 52, no. 1 (March): 35-55.