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Liquidity and leverage ☆

Tobias Adrian [a,*], Hyun Song Shin [b]

[a] Federal Reserve Bank of New York, New York, NY 10045, USA
[b] Princeton University, Princeton, NJ 08544, USA

A R T I C L E I N F O

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A B S T R A C T

In a financial system in which balance sheets are continuously marked to market, asset price changes appear immediately as changes in net worth, and eliciting responses from financial intermediaries who adjust the size of their balance sheets. We document evidence that marked-to-market leverage is strongly procyclical. Such behavior has aggregate consequences. Changes in dealer repos – the primary margin of adjustment for the aggregate balance sheets of intermediaries – forecast changes in financial market risk as measured by the innovations in the Chicago Board Options Exchange Volatility Index VIX index. Aggregate liquidity can be seen as the rate of change of the aggregate balance sheet of the financial intermediaries.

1. Introduction

In a financial system where balance sheets are continuously marked to market, changes in asset prices show up immediately on balance sheets, and have an instant impact on the net worth of all constituents of the financial system. The net worth of financial intermediaries are especially sensitive to fluctuations in asset prices given the highly leveraged nature of such intermediaries' balance sheets.

Our focus in this paper is on the reactions of the financial intermediaries to changes in their net worth, and the market-wide consequences of such reactions. If financial intermediaries were passive

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* Corresponding author.
E-mail addresses: tobias.adrian@ny.frb.org (T. Adrian), hsshin@princeton.edu (H.S. Shin).

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and did not adjust their balance sheets to changes in net worth, then leverage would fall when total assets rise. Change in leverage and change in balance sheet size would then be negatively related.

However, as we will see below, the evidence points to a strongly *positive* relationship between changes in leverage and changes in balance sheet size. Far from being passive, the evidence points to financial intermediaries adjusting their balance sheets actively, and doing so in such a way that leverage is high during booms and low during busts. That is, leverage is procyclical.

Procyclical leverage can be seen as a consequence of the active management of balance sheets by financial intermediaries who respond to changes in prices and measured risk. For financial intermediaries, their models of risk and economic capital dictate active management of their overall Value-at-Risk (VaR) through adjustments of their balance sheets.

From the point of view of each institution, decision rules that result in procyclical leverage are readily understandable. However, there are aggregate consequences of such behavior for the financial system as a whole that might not be taken into consideration by individual institutions. We exhibit evidence that procyclical leverage affects aggregate volatility and particularly the price of risk.

Our paper has two main objectives. Our first objective is to document the relationship between balance sheet size and leverage for security broker dealers – financial intermediaries that operate primarily through the capital markets, and which included the major Wall Street investment banks. We show that leverage is strongly procyclical for these institutions and show that the margin of adjustment on the balance sheet is through repos and reverse repos. The first version of our paper was written in June 2007, just prior to the eruption of the financial crisis of 2007–2009. Since then, the five major US investments banks that we analyze in the remainder of the paper have all left the broker dealer sector. Three of them – Bear Stearns, Lehman Brothers and Merrill Lynch were either taken over under distressed conditions or declared bankruptcy. The remaining two – Goldman Sachs and Morgan Stanley – converted to bank holding companies. Thus, in the short time period since the first version of this paper was written, the era of stand alone Wall Street investment banks has come to an end. Our paper represents a contemporaneous record of the last months of the once illustrious Wall Street investment banks.

Our second objective is to pursue the aggregate consequences of procyclical leverage and document evidence that expansions and contractions of balance sheets have asset pricing consequences through shifts in risk appetite. In particular, we show that changes in collateralized borrowing and lending on intermediary's balance sheet are significant forecasting variables for innovations in market-wide risk as measured by the VIX index of implied volatility in the stock market. We also decompose VIX innovations into changes of stock market volatility and changes of the difference between implied volatility and actual volatility (the volatility risk premium). We find that dealer balance sheet changes primarily forecast changes in the volatility risk premium, which has a natural interpretation as the price of risk.

Previous work has shown that innovations in market volatility are important cross-sectional pricing factors (see Ang et al. (2006), and Adrian and Rosenberg (2008)), and that the volatility risk premium forecasts future equity returns (Bollerslev and Zhou (2007)). Our finding that fluctuations of the balance sheets of broker dealers forecast volatility innovations shows that intermediary balance sheets matter for the pricing of risk. In this way, our empirical results provide some backing to recent theoretical work on liquidity and asset pricing. Gromb and Vayanos (2002) draw on the theme in Shleifer and Vishny (1997) on the importance of collateral constraints for leveraged traders. Brunnermeier and Pedersen (2009) coined the term "margin spiral" where increased margins and falling prices reinforce market distress. He and Krishnamurthy (2008) show how intermediary capital matters in a dynamic asset pricing model. Our empirical results provide some context for this literature.

Our findings also shed light on the concept of "liquidity" as used in common discourse about financial market conditions. In the financial press and other market commentary, asset price booms are sometimes attributed to "excess liquidity" in the financial system. Financial commentators are fond of using the associated metaphors, such as the financial markets being "awash with liquidity", or liquidity "sloshing around". However, the precise sense in which "liquidity" is being used in such contexts is often left unspecified.

Our empirical findings suggest that financial market liquidity can be understood as the rate of growth of aggregate balance sheets. In response to increases in prices on the asset side of intermediaries' balance sheets, leverage falls, and intermediaries hold surplus capital. They will then search for uses of their surplus capital. In a loose analogy with manufacturing firms, we may see the financial system as having "surplus capacity". For such surplus capacity to be utilized, the intermediaries expand their balance sheets. On the liabilities side, they take on more short-term debt. On the asset side, they search for potential borrowers that they can lend to. Financial market liquidity is intimately tied to how hard the financial intermediaries search for borrowers.

The outline of our paper is as follows: we begin with a review of some very basic balance sheet arithmetic on the relationship between leverage and total assets. The purpose of this initial exercise is to motivate our empirical investigation of the balance sheet changes of financial intermediaries in Section 3. Having outlined the facts, in Section 4, we show that changes in aggregate repo positions of the major financial intermediaries can forecast innovations in the volatility risk-premium, where the volatility risk premium is defined as the difference between the VIX index and realized volatility. We conclude with discussions of the implications of our findings for funding liquidity.

2. Some basic balance sheet arithmetic

What is the relationship between *leverage* and *balance sheet size*? We begin with some very elementary balance sheet arithmetic, so as to focus ideas. Before looking at the evidence for financial intermediaries, let us think about the relationship between balance sheet size and leverage for a household. The household owns a house financed with a mortgage. For concreteness, suppose the house is worth 100, the mortgage value is 90, and so the household has net worth (equity) of 10. The initial balance sheet then is given by:

Assets	Liabilities
House 100	Equity 10 Mortgage 90

Leverage is defined as the ratio of total assets to equity, hence is $100/10 = 10$. What happens to leverage as total assets fluctuate? Denote by A the market value of total assets and E is the market value of equity. We make the simplifying assumption that the market value of debt stays roughly constant at 90 for small shifts in the value of total assets. Total leverage is then

$$L \simeq \frac{A}{A-90}$$

Leverage is inversely related to total assets. When the price of my house goes up, my net worth increases, and so my leverage goes down. Indeed, for households, the negative relationship between total assets and leverage is clearly borne out in the aggregate data. Fig. 1 plots the quarterly changes in total assets to quarterly changes in leverage as given in the Flow of Funds account for the United States. The data are from 1963 to 2006. The scatter chart shows a strongly negative relationship, as suggested by a passive behavior toward asset price changes.

We can ask the same question for firms, and we will address this question for three different types of firms: non-financial firms, commercial banks and security brokers and dealers. If a firm were passive in the face of fluctuating asset prices, then leverage would vary inversely with total assets. However, the evidence points to a more active management of balance sheets.

Fig. 2 is a scatter chart of the change in leverage and change in total assets of non-financial, non-farm corporations drawn from the U.S. flow of funds data (1963–2006). The scatter chart shows much less of a negative pattern, suggesting that companies react somewhat to changes in asset prices by shifting their stance on leverage.[1] More notable still is the analogous chart for U.S. commercial banks, again drawn from the U.S. Flow of Funds accounts. Fig. 3 is the scatter chart plotting changes in leverage

[1] This finding is consistent with Welch's (2004) analysis of non-financial leverage which demonstrates that 40% of leverage changes are (passively) explained by shocks to equity prices, and 60% by the net issuing activity.

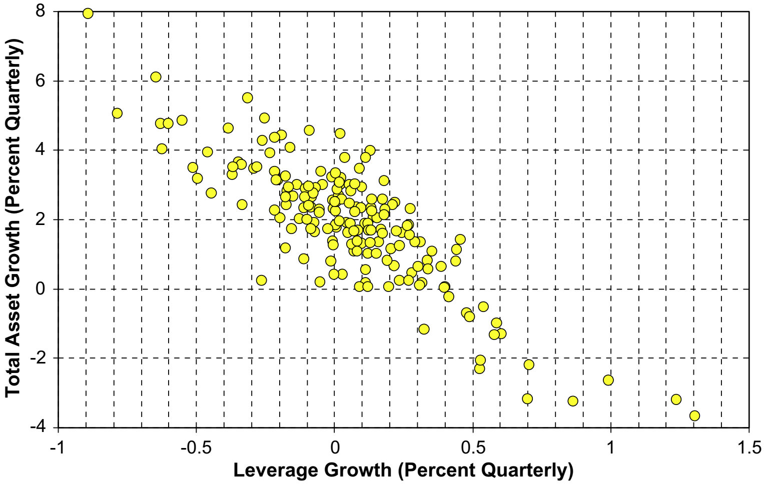


Fig. 1. Total assets and leverage of household.

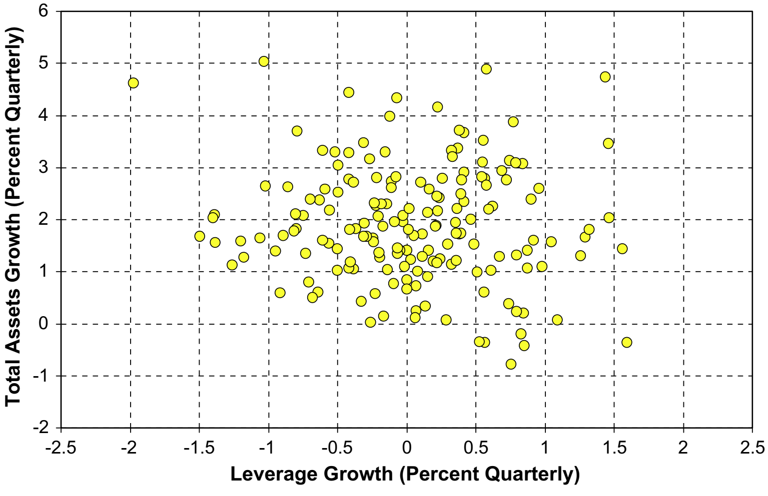


Fig. 2. Total assets and leverage of non-financial, non-farm corporates.

against changes in total assets for U.S. commercial banks. A large number of the observations line up along the vertical line that passes through zero change in leverage. In other words, the data show the outward signs of commercial banks targeting a fixed leverage ratio.

However, even more striking than the scatter chart for commercial banks is that for security dealers and brokers, that include the major Wall Street investment banks. Fig. 4 is the scatter chart for U.S. security dealers and brokers, again drawn from the Flow of Funds accounts (1963–2006). The alignment of the observations is now the reverse of that for households. There is a strongly *positive* relationship between changes in total assets and changes in leverage. In this sense, leverage is procyclical.

In order to appreciate the aggregate consequences of procyclical leverage, let us first consider the behavior of a financial intermediary that manages its balance sheet actively to as to maintain a *constant* leverage ratio of 10. The effects we describe below will be even larger for leverage that is

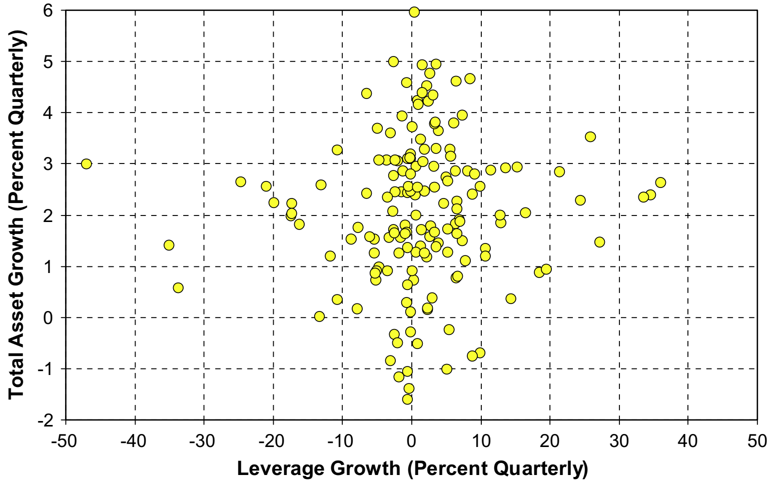


Fig. 3. Total assets and leverage of commercial banks.

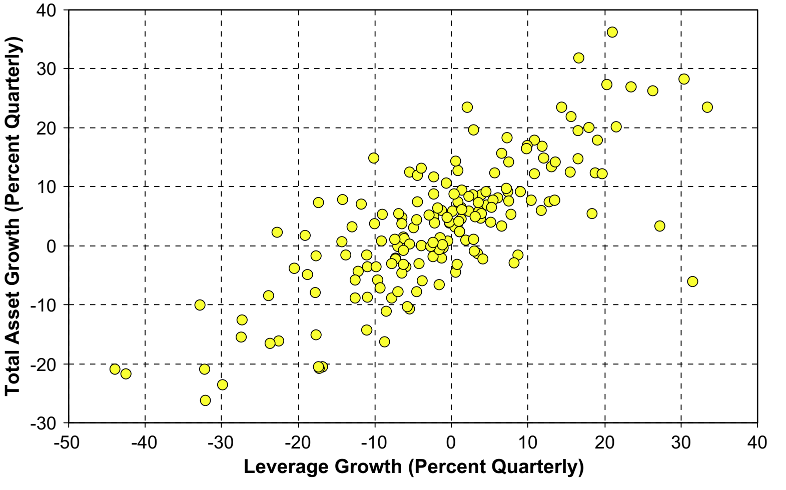


Fig. 4. Total assets and leverage of security brokers and dealers.

procyclical. Suppose the initial balance sheet is as follows. The financial intermediary holds 100 worth of securities, and has funded this holding with debt worth 90.

Assets	Liabilities
Securities, 100	Equity, 10 Debt, 90

Assume that the price of debt is approximately constant for small changes in total assets. Suppose the price of securities increases by 1% to 101.

Assets	Liabilities
Securities, 101	Equity, 11 Debt, 90

Leverage then falls to $101/11 = 9.18$. The bank targets leverage of 10, and so takes on additional debt of D to purchase D worth of securities on the asset side so that

$$\frac{\text{assets}}{\text{equity}} = \frac{101 + D}{11} = 10$$

The solution is $D = 9$. The bank takes on additional debt worth 9, and with this money purchases securities worth 9. Thus, an increase in the price of the security of 1 leads to an increased holding worth 9. After the purchase, leverage is now back up to 10.

Assets	Liabilities
Securities, 110	Equity, 11 Debt, 99

The mechanism works in reverse, too. Suppose there is shock to the securities price so that the value of security holdings falls to 109. On the liabilities side, it is equity that bears the burden of adjustment, since the value of debt stays approximately constant.

Assets	Liabilities
Securities, 109	Equity, 10 Debt, 99

Leverage is now too high $(109/10 = 10.9)$. The bank can adjust down its leverage by selling securities worth 9, and paying down 9 worth of debt. Thus, a *fall* in the price of securities of leads to *sales* of securities. The new balance sheet then looks as follows. The balance sheet is now back to where it started before the price changes. Leverage is back down to the target level of 10.

Assets	Liabilities
Securities, 100	Equity, 10 Debt, 90

The perverse nature of the reactions to price changes are even stronger when the leverage of the financial intermediary is procyclical. When the securities price goes up, the upward adjustment of leverage entails purchases of securities that are even larger than that for the case of constant leverage. If there is the possibility of feedback, then the adjustment of leverage and price changes will reinforce each other in an amplification of the financial cycle.

If financial markets are not perfectly liquid so that greater demand for the asset tends to put upward pressure on its price, then there is the potential for a feedback effect in which stronger balance sheets feed greater demand for the asset, which in turn raises the asset's price and lead to stronger balance sheets. Fig. 5 illustrates the feedback during a boom. The mechanism works exactly in reverse in downturns. If financial markets are not perfectly liquid so that greater supply of the asset tends to put downward pressure on its price, then there is the potential for a feedback effect in which weaker balance sheets lead to greater sales of the asset, which depresses the asset's price and lead to even weaker balance sheets. Fig. 6 illustrates the feedback during a downturn.

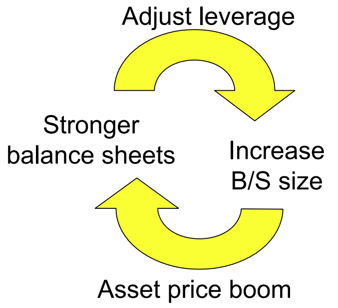


Fig. 5. Leverage adjustment in upturn.

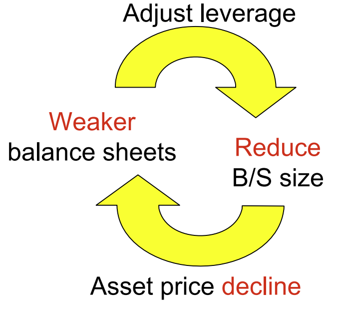


Fig. 6. Leverage adjustment in downturn.

In Section 4, we return to the issue of feedback by exhibiting evidence that is consistent with the amplification effects sketched above. We will see that changes in key balance sheet components forecast changes in the VIX index of implied volatility in the stock market.

3. A first look at the evidence

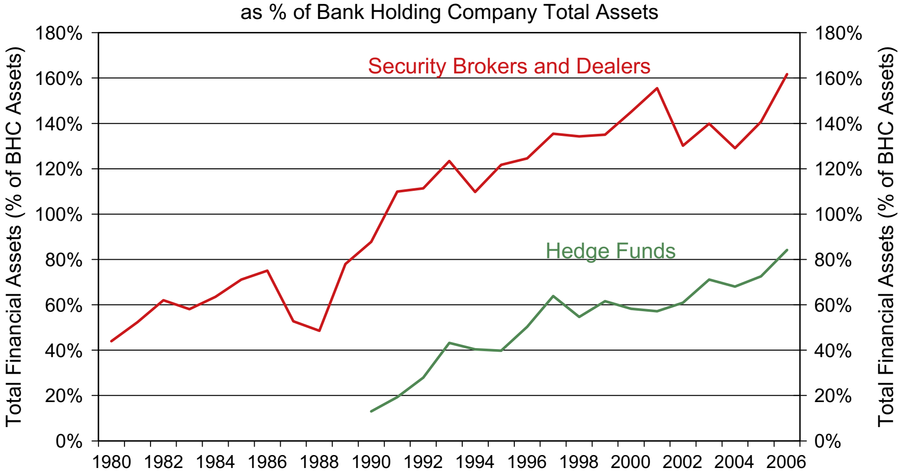
3.1. Investment bank balance sheets

To set the stage for our empirical study, we begin by examining the quarterly changes in the balance sheets of the (then) five major US investment banks, as listed below in Table 1. The data are from the regulatory filings with the U.S. Securities and Exchange Commission (SEC) on their 10-K and 10-Q forms.

Our choice of these five banks is motivated by our concern to examine "pure play" investment banks that were not part of bank holding companies so as to focus attention on their behavior with

Table 1
Investment banks.

Name	Sample
Bear Stearns	1997Q1–2008Q1
Goldman Sachs	1999Q2–2008Q1
Lehman Brothers	1993Q2–2008Q1
Merrill Lynch	1991Q1–2008Q1
Morgan Stanley	1997Q2–2008Q1



Source:
Total financial assets of Security Brokers and Dealers are from table L.129 of the Flow of Funds, Board of Governors of the Federal Reserve.
Total financial assets of Bank Holding Companies are from table L.112 of the Flow of Funds, Board of Governors of the Federal

Fig. 7. Total financial intermediary assets.

respect to the capital markets.[2] Citigroup reported its investment banking operations separately from its commercial banking operations until 2004 as "Citigroup Global Markets", and we have data for the period 1998Q1–2004Q4. In some of our charts below, we will report Citigroup Global Markets for comparison. The stylized balance sheet of an investment bank is as follows.

Assets	Liabilities
Trading assets	Short positions
Reverse repos	Repos
Other assets	Long term debt
	Shareholder equity

On the asset side, traded assets are valued at market prices, or are short term collateralized loans (such as reverse repos) for which the discrepancy between face value and market value are very small due to the very short term nature of the loans. On the liabilities side, short positions are at market values, and repos are very short term borrowing. We will return to a more detailed descriptions of repos and reverse repos below. Long-term debt is typically a small fraction of the balance sheet for investment banks.[3] For these reasons, investment banks provide a good approximation of the balance sheet that is continuously marked to market, and hence provide insights into how leverage changes with balance sheet size.

The second reason for our study of investment banks lies in their increasing significance for the financial system until the financial crisis that led to the demise of the large investment banks. Fig. 7 plots the size of securities firms' balance sheets relative to that of bank holding companies. We also plot the assets under management for hedge funds, although we should be mindful that

[2] Hence, we do not include JP Morgan Chase, Credit Suisse, Deutsche Bank, and other brokerage operations that are part of a larger bank holding companies.

[3] The balance sheet of Lehman Brothers as of November 2005 shows that short positions are around a quarter of total assets, and long term debt is an even smaller fraction. Shareholder equity is around 4% of total assets (implying leverage of around 25). Short-term borrowing in terms of repurchase agreements and other collateralized borrowing takes up the remainder.

"assets under management" refers to total investor equity, rather than the size of the balance sheet. To obtain total balance sheet size, we should multiply by hedge fund leverage (which is not readily available). Fig. 7 shows that when expressed as a proportion of bank holding company balance sheets, securities firms had been increasing their balance sheets at a very rapid rate. Note that when hedge funds' assets under management is converted to balance sheet size by multiplying by a conservative leverage factor of 2, the combined balance sheets of investment banks and hedge funds overtook the bank holding company balance sheets in 1990, and became more that twice as large by 2007.

Size is not the only issue. When balance sheets are marked to market, the responses to price changes may entail responses that may be disproportionately large. LTCM's balance sheet was small relative to the total financial sector, but its impact would have been underestimated if only size had been taken into account. Similarly, the size of the sub-prime mortgage exposures was small relative to the liabilities of the financial system as a whole, but the credit crisis of 2007/2008 demonstrates that its impact can be large. Table 2 gives the summary statistics of the investment banks over the sample period.

We begin with the key question left hanging from the previous section. What is the relationship between leverage and total assets? The answer is provided in the scatter charts in Fig. 8. We have included the scatter chart for Citigroup Global Markets (1998Q1–2004Q4) for comparison, although Citigroup does not figure in the panel regressions reported below. The scatter chart shows the growth in assets and leverage at a quarterly frequency. In all cases, leverage is large when total assets are large. Leverage is procyclical.

There are some notable common patterns in the scatter charts, but also some notable differences. The events of 1998 are clearly evident in the scatter charts. The early part of the year saw strong growth in total assets, with the attendant increase in leverage. However, the third and fourth quarters of 1998 shows all the hallmarks of financial distress and the attendant retrenchment in the balance sheet. For most banks, there were very large contractions in balance sheet size in 1998Q4, accompanied by large falls in leverage. These points are on the bottom left hand corners of the respective scatter charts, showing large contractions in the balance sheet and decrease in leverage. Lehman Brothers and Merrill Lynch seem especially hard hit in 1998Q4.

Table 2
Investment bank summary statistics.

	Mean	Std Dev	Min	Median	Max	Obs
Panel A: US$ Millions						
Total assets	344599	217085	97302	287562	901397	65
Total liabilities	330937	208964	93111	275719	871561	65
Equity	13289	8365	4190	10988	30920	65
Reverse repos and other collateralized lending	134923	80723	34216	116731	323802	65
Reverse repos	64368	30615	19097	55911	140054	65
Repos and other collateralized borrowing	105948	60501	29423	89189	263724	65
Repos	98474	41596	54682	83227	202372	53
Trading VaR	49	17	29	45	92	29
Panel B: quarterly growth						
Total assets	4%	5%	−15%	4%	16%	64
Total liabilities	4%	5%	−15%	4%	17%	64
Equity	3%	3%	−5%	3%	8%	64
Reverse repos and other collateralized lending	4%	7%	−19%	3%	21%	64
Reverse repos	3%	9%	−16%	3%	28%	64
Repos and other collateralized borrowing	3%	9%	−26%	4%	21%	64
Repos	2%	9%	−19%	1%	19%	53
Trading VaR	4%	9%	−25%	3%	19%	28

This Table reports aggregate balance sheet items for the five investment banks of Table 1. In Panel A, we report time series summary statistics for the cross sectional average of the balance sheet items. In Panel B, we report the summary statistics of quarterly grwoth rates which are weighted by the total assets cross sectionally.

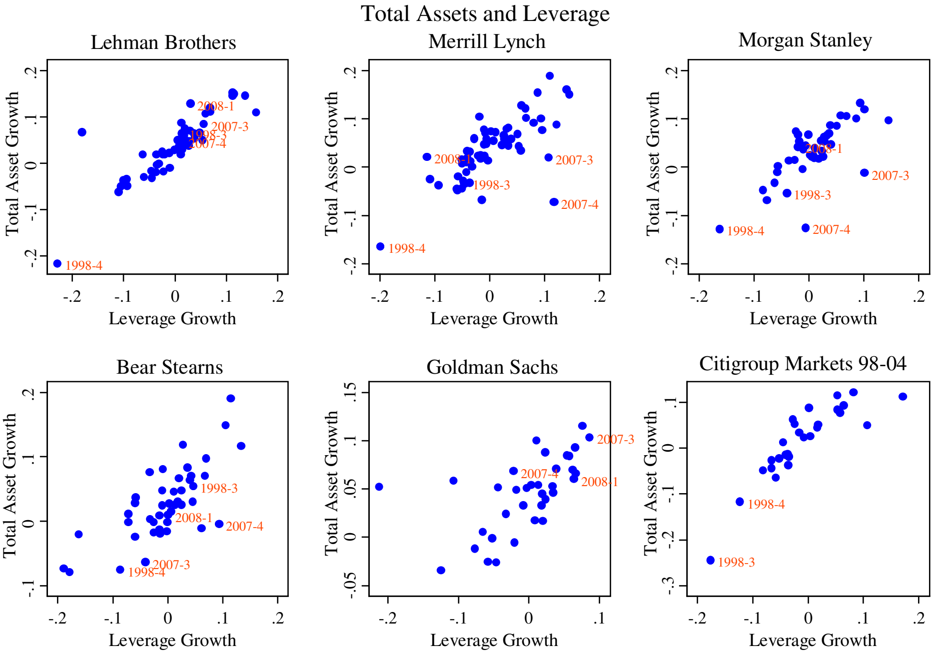


Fig. 8. Total assets and leverage.

However, there are also some notable differences. It is notable, for instance, that for Citigroup Global Markets, the large retrenchment seems to have happened in the third quarter of 1998, rather than in the final quarter of 1998. Such a retrenchment would be consistent with the closing down of the former Salomon Brothers fixed income arbitrage desk on July 6th 1998, following the acquisition of the operation by Travelers Group (later, Citigroup). Many commentators see this event as the catalyst for the sequence of events that eventually led to the demise of Long Term Capital Management (LTCM) and the associated financial distress in the summer and early autumn of 1998.[4]

Fig. 9 aggregates the individual scatter charts by taking the asset-weighted average of changes in balance sheet size and leverage. The upward-sloping relationship between changes in assets and changes in leverage is clearer. The 45-degree line in the scatter chart corresponds to the combination of points where the total equity value remains constant. This is because leverage growth is defined as the log difference in assets minus log difference in equity. Hence, the 45-degree line corresponds to the points where the log difference in equity is zero. The set of points below the 45-degree line corresponds to the observations in which equity fell. This explains why the observations for the third and fourth quarters of 2007 appear below the 45-degree line, as banks announced credit losses on their mortgage portfolios. More interestingly, there is a striking contrast between what happened in 1998 following the LTCM crisis and the credit crisis of 2007/2008. As of the first quarter of 2008, there had not been the same type of contraction of balance sheets as was observed in the 1998 crisis. This difference holds the key to several distinctive characteristics of the crisis of 2007/2008, as shown by Adrian and Shin (2008a) and Greenlaw et al. (2008).

Table 3 shows the results of a panel regression for change in leverage. The positive relationship between the change in leverage and change in total assets is confirmed in column (ii) of Table 3. The coefficient on lagged leverage (i.e. previous quarter's leverage) is negative, suggesting that leverage is mean-reverting. Leverage is negatively related to lagged Value-at-Risk (final column).

[4] The official account (BIS, 1999) is given in the report of the CGFS of the Bank for International Settlements (the so-called "Johnson Report"). Popular accounts, such as Lowenstein (2000) give a description of the background and personalities.

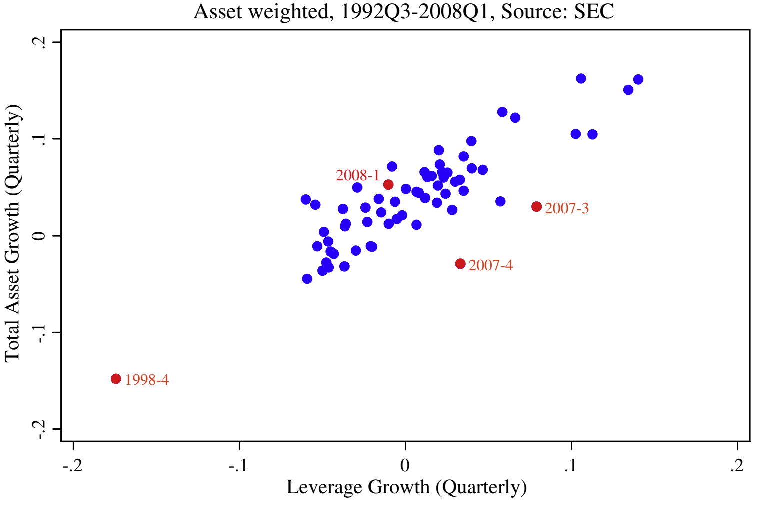


Fig. 9. Aggregate leverage and total asset growth.

Table 3
Leverage regressions.

		Leverage (quarterly growth)			
		(i)	(ii)	(iv)	(v)
Leverage (log lag)	Coef	−0.08	−0.04	−0.07	−0.02
	p-Value	0.00	0.02	0.04	0.82
Total Assets (quarterly growth)	Coef		0.83		
	p-Value		0.00		
Repos (quarterly growth)	Coef			0.22	
	p-Value			0.00	
Trading VaR (quarterly growth, lag)	Coef				−0.06
	p-Value				0.01
Constant	Coef	0.28	0.09	0.21	0.07
	p-Value	0.00	0.06	0.04	0.77
Observations		235	235	196	109
Number of banks		5	5	5	5
R^2		5%	62%	24%	5%
Fixed effects		Yes	Yes	Yes	Yes

This table reports panel regressions of quarterly leverage growth rates on the lagged level of leverage, the growth rates of trading VaRs, the growth rates of repos, and the growth rates of total assets. Leverage is computed from the balance sheets of the five investment banks from Table 1 whose summary statistics are reported in Table 2. Leverage is defined as the ratio of total assets to book equity. All of the balance sheet data are from the 10-K and 10-Q filings of the banks with the Security and Exchange Commission. *p*-values are adjusted for autocorrelation and heteroskedasticity.

More interestingly, third column of Table 3 shows that the margin of adjustment in the fluctuations of balance sheets is through repos. In a repurchase agreement (repo), a financial institution sells a security on the understanding that it will buy it back at a pre-agreed price on a fixed future date. Such an agreement is tantamount to a collateralized loan, with the interest on the loan being the excess of the repurchase price over the sale price. From the perspective of the funds lender – the party who buys the security with the undertaking to re-sell it later – such agreements are called reverse repos. For the buyer, the transaction is equivalent to granting a loan, secured on collateral. In this way, adjustments in total assets and hence leverage show up as changes in repos, as is visible in Fig. 10.

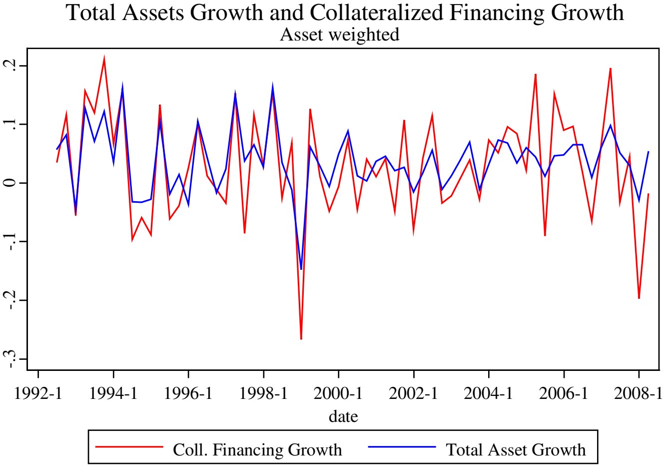


Fig. 10. Total asset and total repo growth.

Repos and reverse repos are important financing activities that provide the funds and securities needed by investment banks to take positions in financial markets. For example, a bank taking a long position by buying a security needs to deliver funds to the seller when the security is received on settlement day. If the dealer does not fully finance the security out of its own capital, then it needs to borrow funds. The purchased security is typically used as collateral for the cash borrowing. When the bank sells the security, the sale proceeds can be used to repay the lender.

Reverse repos are loans made by the investment bank against collateral. The bank's prime brokerage business vis-à-vis hedge funds will figure prominently in the reverse repo numbers. The scatter chart gives a glimpse into the way in which changes in leverage are achieved through expansions and contractions in the collateralized borrowing and lending. We saw in our illustrative section on the elementary balance sheet arithmetic that when a bank wishes to expand its balance sheet, it takes on additional debt, and with the proceeds of this borrowing takes on more assets. The expansion and contraction of total assets via repos are plotted in Fig. 11.

Fig. 11 plots the change in assets against change in collateralized borrowing for each of the investment banks. The positive relationship in the scatter plot confirms our panel regression finding that balance sheet changes are accompanied by changes in short term borrowing.

Fig. 12 plots the change in repos against the change in reverse repos. A dealer taking a short position by selling a security it does not own needs to deliver the security to the buyer on the settlement date. This can be done by borrowing the needed security, and providing cash or other securities as collateral. When the dealer closes out the short position by buying the security, the borrowed security can be returned to the securities lender. The scatter plot in Fig. 12 suggests that repos and reverse repos play such a role as counterparts in the balance sheet.

3.2. Value-at-Risk

Procyclical leverage is not a term that the banks themselves are likely to use in describing what they do, although this is in fact what they are doing. To get a better handle on what motivates the banks in their actions, we explore the role of Value-at-Risk (VaR) in explaining the banks' balance sheet decisions.

For a random variable A, the *Value-at-Risk* at confidence level c relative to some base level A_0 is defined as the smallest non-negative number VaR such that

$$\text{Prob}(A < A_0 - VaR) \leqslant 1 - c$$

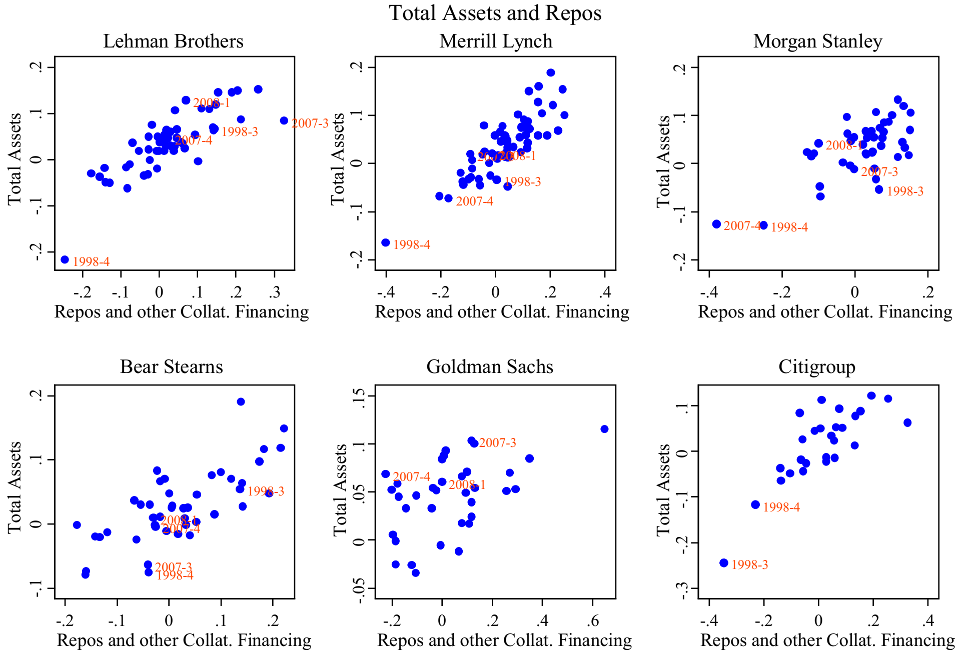


Fig. 11. Total assets and repos.

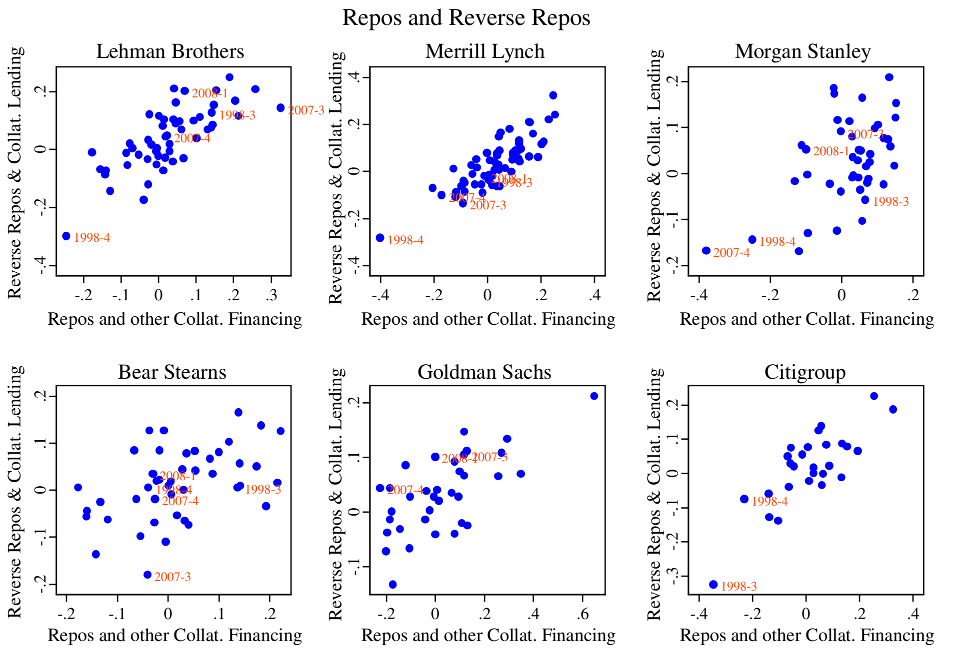


Fig. 12. Repos and reverse repos.

For instance, A could be the total marked-to-market assets of the firm at some given time horizon. Then the Value-at-Risk is the equity capital that the firm must hold in order to stay solvent with probability c. Financial intermediaries publish their Value-at-Risk numbers as part of their regulatory filings and in their annual reports. Their *economic capital* is tied to the overall Value-at-Risk of the whole firm, where the confidence level is set at a level high enough to target a given credit rating (typically A or AA).

If financial intermediaries adjust their balance sheets to target a ratio of Value-at-Risk to economic capital, then we may conjecture that their disclosed Value-at-Risk figures would be informative in reconstructing their actions. If the bank maintains capital K to meet total Value-at-Risk, then we have

$$K = \lambda \times VaR \tag{3.1}$$

where λ is the proportion of capital that the intermediary holds per unit of VaR. The proportionality λ is potentially time varying. Hence, leverage L satisfies

$$L = \frac{A}{K} = \frac{1}{\lambda} \times \frac{A}{VaR} = \frac{1}{\lambda} \times \frac{1}{V}$$

where V is the *unit value-at-risk*, defined as the value-at-risk per dollar of assets. Procyclical leverage then follows directly from the *counter*-cyclical nature of unit value-at-risk. The negative relationship between leverage and value-at-risk can also be seen in Table 3, column (v).

We can indeed see this counter-cyclical relationship in the data. In Fig. 13, we plot the unit value-at-risk against total assets, having removed the fixed effects for individual banks. We see that the relationship is downward sloping. We highlight 2007Q4 and 2008Q1 for Bear Stearns and Lehman Brothers, as they are clear outliers in the plot. The high levels of unit value-at-risk for these two investment banks leading up to the height of the credit crisis is suggestive of balance sheets that are under considerable stress. Shortly after filing its 10-Q form for the first quarter of 2008, Bear Stearns suffered its run, and was acquired by J.P. Morgan Chase with the assistance of the Federal Reserve. Lehman Brothers filed for bankruptcy in September of 2008.

In Fig. 14, we plot the evolution of the average unit value-at-risk over time. We see again that the average unit value-at-risk increased sharply in 2007Q4 and 2008Q1.

Eq. (3.1) also suggests that the ratio of Value-at-Risk to shareholder equity may be an informative series to track over time. The naive hypothesis would be that this ratio is kept constant over time by the bank. The naive hypothesis also ties in neatly the regulatory capital requirements under the 1996

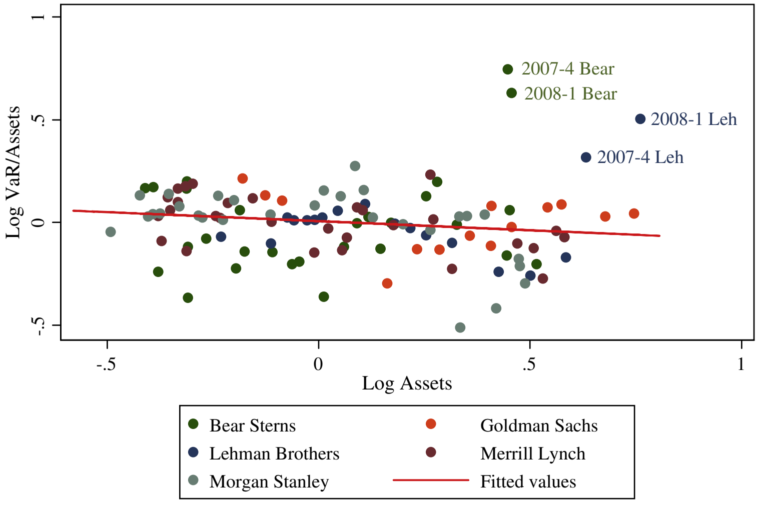


Fig. 13. VaR and total assets.

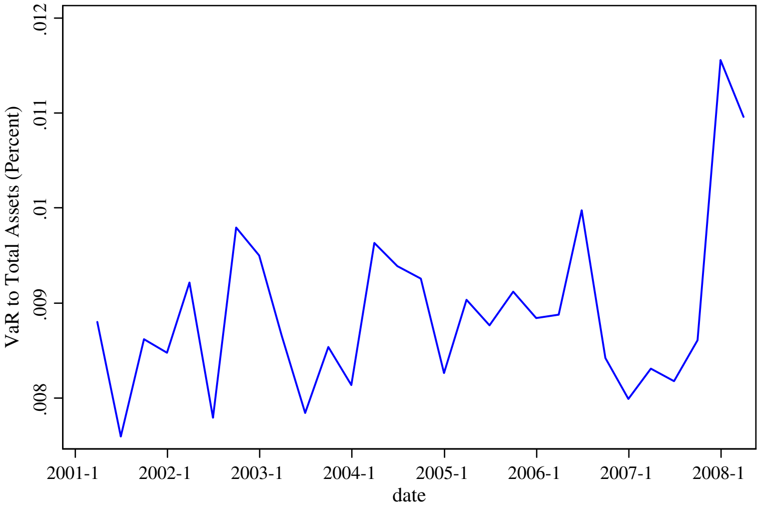


Fig. 14. VaR to total assets (percent).

Market Risk Amendment of the Basel capital accord. Under this rule, the regulatory capital is three times the 10 day, 99% Value-at-Risk.

In Fig. 15, we plot the evolution of the VaR/equity ratio and leverage over time. The Value-at-Risk numbers are reported in the 10-K and 10-Q filings since 2001. We can see that both ratios – VaR/Equity and Leverage – are fairly constant before 2007, with the exception of Goldman Sachs, which exhibits a marked increase in leverage. In 2007, both leverage and the VaR/equity ratio increased markedly for most banks. In Fig. 16, we plot average leverage for all banks since 1992. There are two peaks in the

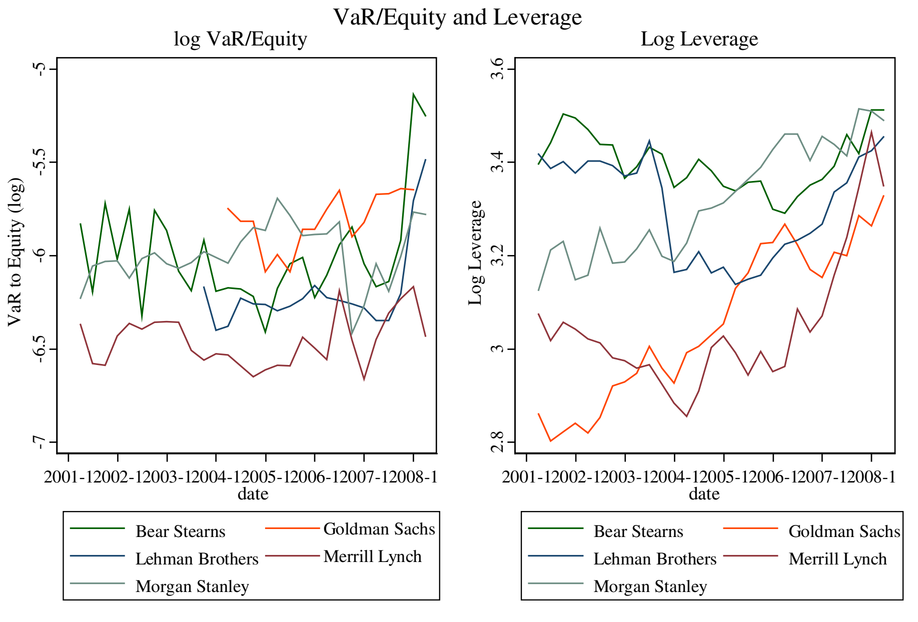


Fig. 15. VaR/equity and leverage.

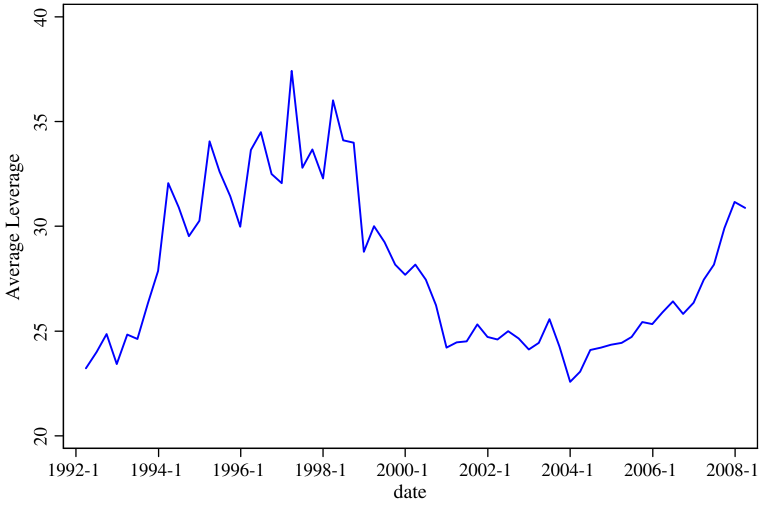


Fig. 16. Average leverage over time.

evolution of leverage over time, one prior to the LTCM crisis of 1998, and a second peak in the run-up to the global financial crisis of 2007–2009.

4. Forecasting risk appetite

We now explore the asset pricing consequences of balance sheet fluctuations. We exhibit empirical evidence that the waxing and waning of balance sheets have a direct impact on asset prices through the ease with which traders, hedge funds and other users of credit can obtain funding for trades.

So far, we have used quarterly data drawn either from the balance sheets of individual financial intermediaries or the aggregate balance sheet items from the Flow of Funds accounts. However, for the purpose of tracking the financial market consequences of balance sheet adjustments, data at a higher frequency are more useful. For this reason, we use the weekly data on the primary dealer repo and reverse repo positions compiled by the Federal Reserve Bank of New York. The primary dealer data have previously been analyzed by Adrian and Fleming (2005) and Kambhu (2006).

Primary dealers are security-broker dealers with whom the Federal Reserve has a trading relationship. The primary dealers include the (then) five investment banks studied above, as well as commercial and foreign banks that own broker-dealers.[5] The Federal Reserve collects transactions, positions, financing, and settlement data of the primary dealers in fixed income markets. The data are consolidated and released publicly on the Federal Reserve Bank of New York website.[6] The primary dealer data provide a valuable window on the overall market, at a frequency (every week) that is much higher than the usual quarterly reporting cycle. Dealers collect information on their financing activities each Wednesday; summary data are released each Thursday, one week after they are collected. The data are aggregated across all dealers, and are only available by asset class.

Repos and reverse repos are a subset of the security financing data. Financing distinguishes between "securities in" and "securities out" for each asset class. "Securities in" refer to securities received by a dealer in a financing arrangement, whereas "securities out" refer to securities delivered by a dealer in a financing arrangement. For example, if a dealer enters into a repo, in which it borrows funds and provides securities as collateral, it would report securities out. Repos and reverse repos are

[5] A list of current primary dealers can be found at: http://www.newyorkfed.org/markets/pridealers_current.html.

[6] www.newyorkfed.org/markets/primarydealers.html.

reported across all sectors. Adrian and Fleming (2005) provide more detail about the data, and see Duffie (1996) and Fleming and Garbade (2003) for further details about repo markets.

We use the weekly repo and reverse repo data to forecast financial market conditions in the following week. Our measure of financial market conditions is the VIX index of implied volatility in S&P500 index options. The VIX index reflects aggregate financial market volatility, as well as the price of risk of market volatility. Ang et al. (2006) show that VIX innovations are significant pricing factors for the cross section of equity returns, and Bollerslev and Zhou (2007) show that the volatility risk premium – the difference between the VIX and realized volatility of the S&P500 index – forecasts equity returns better than other commonly used forecasting variables (such as the P/E ratio or the term spread). We provide summary statistics of the primary dealer data, and the volatility data in Table 4.

We use the daily VIX data from the website of the Chicago Board Options Exchange (www.cboe.com/micro/vix), and compute the S&P500 volatility from daily data over weekly windows. We compute the volatility risk premium as the difference between implied volatility and realized volatility. This risk premium is closely linked to the payoff to volatility swaps, which are zero investment derivatives that return the difference between realized future volatility and implied volatility over the maturity of the swap (see Carr and Wu (2009) for an analysis of variance and volatility swaps). We then compute averages of the VIX and the variance risk premium over each week (from the close of Wednesday to the close of the following Tuesday).

The growth rate of repos on dealers' balance sheets significantly forecast innovations in the VIX. This can be seen in column (ii) of Table 5, where we report forecasting regressions for VIX changes over the next week. The forecasting results are significant at the 1% level. The forecasting R^2 increases from 4.9% when only the past VIX level is used, to 9% when repo changes are included in the forecast (comparison of columns i and ii). We believe the latter result (the significant forecasting power of dealer's repo growth for innovations in implied volatility) to be important. The forecasting result also holds for reverse repos, consistent with the notion that it is the total size of the balance sheet that matters for aggregate liquidity (column ii).

In order to gain a better understanding what is determining the forecasting result, we also run the forecasting regressions for S&P500 volatility and the volatility risk premium (columns v–viii). We see that it is the volatility risk premium that is being forecast, not actual equity volatility. Adjustments to the size of financial intermediary balance sheets via repos thus forecasts the price of risk of aggregate volatility, rather than aggregate volatility itself. We provide a graphical illustration of the forecasting power of repos as a scatter chart in Fig. 17.

We can put forward the following economic rationale for the forecasting regressions presented here. When balance sheets expand through the increased collateralized lending and borrowing by financial intermediaries, the newly released funding resources chase available assets for purchase. More capital is deployed in increasing trading positions through the chasing of yield, and the selling

Table 4
Primary dealer financing summary statistics.

	Mean	Std Dev	Min	Max	Obs
Panel A: US$ Billions					
Reverse repos and other collateralized lending	1708	1026	397	4227	926
Reverse repos	1252	702	332	2972	926
Repos and other collateralized borrowing	1792	1087	382	4616	926
Repos	1736	1086	369	4567	926
Net repos	484	396	21	1600	926
Panel B: weekly growth					
Reverse repos and other collateralized lending	17%	207%	−1075%	1266%	925
Reverse repos	19%	265%	−1410%	1471%	925
Repos and other collateralized borrowing	18%	215%	−1076%	1360%	925
Repos	19%	222%	−1159%	1344%	925
Net repos	40%	437%	−2429%	5356%	925

This table reports summary statistics of collateralized financing by the Federal Reserve's Primary Dealers from form FR2004 for January 3, 1990– April 2, 2008.

Table 5
Forecasting volatility.

		One week average				Volatility (change)		Volatility risk premium (change)	
		Implied volatility (change)							
		(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Implied volatility (lag)	Coef	−0.10	−0.09	−0.09	−0.10	−0.45	−0.45	−0.81	−0.81
	p-value	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Repos (lagged growth)	Coef		−0.28				0.01		−0.21
	p-value		0.00				0.89		0.05
Reverse repos (lagged growth)	Coef			−0.24					
	p-value			0.00					
Net repos (lagged growth)	Coef				−0.06				
	p-value				0.00				
Constant	Coef	1.95	1.85	1.82	1.93	4.99	4.96	6.50	6.52
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
R^2 (adj.)		4.9%	9.0%	9.1%	5.5%	22.3%	22.0%	40.3%	41.0%

This table reports forecasting regressions of VIX implied volatility changes, S&P500 volatility changes, and the volatility risk premium on lagged growth rates of repo, reverse repo, and net repo positions of U.S. Primary Dealers. The VIX is computed from the cross section of S&P500 index option prices by the Chicago Board of Options Exchange. We compute weekly volatility from S&P500 returns. The volatility risk premium is the difference between the average VIX over the week and S&P500 volatility for the same week. Summary statistics of the Primary Dealer financing data are given in Table 4. The data are weekly from January 3, 1990–April 2, 2008. *p*-Values are adjusted for autocorrelation and heteroskedasticity.

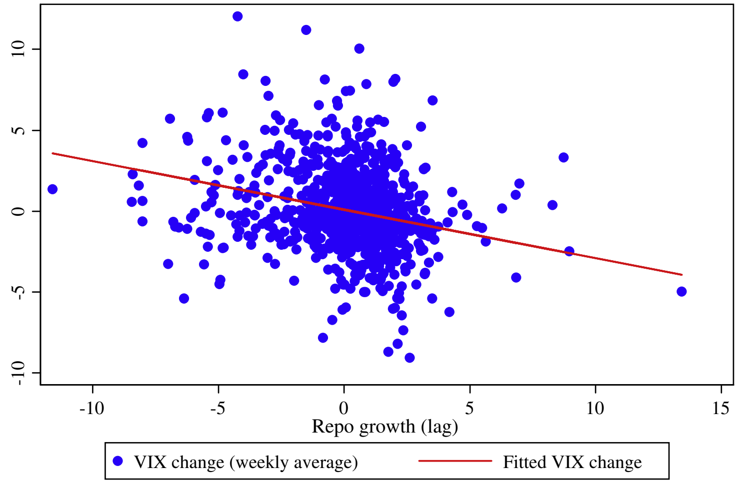


Fig. 17. Implied volatility and lagged repos.

of the "tails" , as in the selling volatility via options. If the increased funding for asset purchases result in the generalized increase in prices and risk appetite in the financial system, then the expansion of balance sheets will eventually be reflected in the asset price changes in the financial system – hence, the ability of changes in repo positions to forecast future volatility, and particularly the volatility risk premium.

Finally, we may expect that balance sheet changes will have an impact on real variables also, such as the components of GDP. This is confirmed in Adrian and Shin (2008b), who study implications for the conduct of monetary policy. We do not pursue this issue further here, for lack of space.

5. Other related literature

Our results add to the literature on the role of liquidity in asset pricing. Gennotte and Leland (1990) and Geanakoplos (2003) provide early analyses that are based on competitive equilibrium. As well as those mentioned in the opening to our paper, recent contributions to the role of liquidity in asset pricing include Allen and Gale (2004), Acharya and Pedersen (2005), Brunnermeier and Pedersen (2005, 2009), Morris and Shin (2004), Diamond and Rajan (2005). The common thread is the relationship between funding conditions and the resulting market prices of assets. Closely related is the literature examining financial distress and liquidity drains.

The managing of leverage is closely tied to the bank's attempt to target a particular credit rating. To the extent that the "passive" credit rating should fluctuate with the financial cycle, the fact that a bank's credit rating remains constant through the cycle suggests that banks manage their leverage actively, so as to shed exposures during downturns. Kashyap and Stein (2003) draw implications from such behavior for the procyclical impact of the Basel II bank capital requirements.

More broadly, our discussion here is related to the large literature on the amplification of financial shocks through balance sheet channels. The literature has distinguished two distinct channels. The first is the increased credit that operates through the *borrower's* balance sheet, where increased lending comes from the greater creditworthiness of the borrower (Bernanke and Gertler (1989), Kiyotaki and Moore (1997, 2005)). The second is the channel that operates through the *banks'* balance sheets, either through the liquidity structure of the banks' balance sheets (Bernanke and Blinder (1988), Kashyap and Stein (2000)), or the cushioning effect of the banks' capital (Van den Heuvel (2002)). Our discussion is closer to the latter group in that we also focus on the intermediaries' balance sheets. However, the added insight from our discussions is on the way that marking to market enhances the role of market prices, and the responses that price changes elicit from intermediaries.

The impact of remuneration schemes on the amplifications of the financial cycle have been addressed recently by Rajan (2005). The agency problems within a financial institution holds important clues on how we may explain procyclical behavior. Stein (1997) and Scharfstein and Stein (2000) present analyses of the capital budgeting problem within banks in the presence of agency problems.

The possibility that a market populated with Value-at-Risk (VaR) constrained traders may have more pronounced fluctuations has been examined by Danielsson et al. (2004). Mark-to-market accounting may at first appear to be an esoteric question on measurement, but we have seen that it has potentially important implications for financial cycles. Plantin et al. (2008) present a microeconomic model that compares the performance of marking to market and historical cost accounting systems.

6. Concluding remarks

Aggregate liquidity can be understood as the rate of growth of the aggregate financial sector balance sheet. When asset prices increase, financial intermediaries' balance sheets generally become stronger, and – without adjusting asset holdings – their leverage tends to be too low. The financial intermediaries then hold surplus capital, and they will attempt to find ways in which they can employ their surplus capital. In analogy with manufacturing firms, we may see the financial system as having "surplus capacity". For such surplus capacity to be utilized, the intermediaries must expand their balance sheets. On the liability side, they take on more short-term debt. On the asset side, they search for potential borrowers. Aggregate liquidity is intimately tied to how hard the financial intermediaries search for borrowers. In the sub-prime mortgage market in the United States we have seen that when balance sheets are expanding fast enough, even borrowers that do not have the means to repay are granted credit – so intense is the urge to employ surplus capital. The seeds of the subsequent downturn in the credit cycle are thus sown.

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