WP/10/220

IMF Working Paper

Macroprudential Regulation under Repo Funding

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INTERNATIONAL MONETARY FUND

IMF Working Paper

IMF Institute

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Authorized for distribution by Marc Quintyn

September 2010

Abstract

The use of collateral has become one of the most widespread risk mitigation techniques. While it brings stabilizing effects to the individual lender we argue that it may exacerbate systemic risk through margin call activation. We show how a liquidity shock to the cash lender may propagate as a solvency shock via liquidity hoarding even if the cash lender remains solvent in all states of nature. Albeit a cost-effective response of the cash lender to a liquidity shock, liquidity hoarding may lead to the bankruptcy of its repo counterparties triggering contagion across asset classes. To buttress the resilience of the financial system, we lay out a menu of macroprudential policies that deactivate this channel of financial contagion.

JEL Classification Numbers: G01, G28

Keywords: Repurchase Agreement; Haircut; Margin Call; Liquidity Hoarding; Systemic Risk; Financial Contagion; Macroprudential Regulation.
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[1] The author is grateful to Eric Clifton, Michael Hsu, Andy Jobst, Luc Laeven, Erlend Nier, Noel Sacasa and Jerome Vandenbussche for their comments, Keiichi Kawai for his suggestions, and seminar participants at the IMF Institute. Remaining errors are the author's responsibility.

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I. INTRODUCTION

The use of collateral has become one of the most widespread risk mitigation techniques in global financial markets. Central banks require collateral in most of their refinancing operations. Banking regulation fosters the use of collateral as an instrument to reduce capital requirements. Financial institutions extensively employ collateral in lending transactions, including reverse repos and securities lending programs. Securities lending programs provide yield to their beneficial owners, including central banks and institutional investors, by reinvesting the collateralized cash in the repo market. These practices have contributed to turn the repo market into the largest financial market today. Gross amounts outstanding in 2008 reached $10 trillion in the US (around 70% of GDP), €6 trillion in the euro area (or 65% of GDP), and £662 billion in the UK (about 50% of GDP) according to BIS estimates (2008).

It has been widely acknowledged that the use of collateral brings stabilizing effects to the individual lender. This may have motivated its recognition as a risk mitigation tool by the Basel Committee in its set of standards for microprudential regulation. This paper takes the view that the exclusive focus on risk mitigation for the lending institution misses the generation of vulnerabilities across a chain of borrowing institutions. We argue that the popularity of collateralized lending brings new risks with it because it introduces an automatic negative correlation between asset returns and funding costs. This negative correlation, which is the result of daily remargining practices, can turn a temporary drop in the value of collateral into a credit downgrade for the cash borrower that will raise the cost of issuing debt precisely when its refinancing needs surge to satisfy the margin call.

The use of collateral thus leaves the borrower exposed to sharp downward moves in the value of the posted security. If a margin call is not swiftly satisfied, the lender can terminate unilaterally the contract and seize the collateral, thus prompting the failure of the borrower. Price fluctuations may be independent of the fundamental value of the asset. For example, they can arise as a result of portfolio reallocations because of the higher perceived liquidity of an asset class relative to others in times of stress. According to BIS (2001, 2010) these patterns were observed during recent emerging market crises, the 1987 equity market crash, the market disruptions of the summer of 1998, and the global financial crisis of 2007-09. Alternatively, contagion across asset classes may be due to investors hitting their borrowing constraint and being forced to deleverage all their portfolio holdings (Fostel and Geanakoplos, 2008). As a result, bad news in one sector may cause price drops in other unrelated sectors with independent payoffs. We take the view that what distinguishes financial intermediaries from other types of investors is their holding of a loan book in addition to their trading book. Therefore in a downward market they have the option to hoard liquidity by cutting back lending rather than selling off financial assets at fire-sale prices. The paper shows that, in the absence of credit risk, the former option dominates the latter. While a credit squeeze helps arresting the loss spiral of the financial intermediary it does so at the expense of precipitating the deleveraging of illiquid assets held by its borrowing counterparties. This is the model of contagion presented in the paper. This result suggests the existence of a trade-off between the beneficial impact of collateral for the lending institution and the risk imposed on the borrowing institutions. In our view, this warrants a review of the role of collateral in the design of macroprudential regulation to ensure the stability of the overall financial system.

As a case in point, consider a large regulated bank with a book of overnight loans financed in the unsecured interbank market and a trading book financed through collateralized borrowing subject to daily remargining. When hit by a margin call, the bank may consider borrow equivalent securities to restore the initial margin ratio agreed in the borrowing transaction. But the risk of a credit downgrade in a falling market raises the cost of issuing new debt. In the absence of cash assets on its balance sheet, the bank may envisage two options. The first is to sell part of the trading book to repay the debt being called. The second is to shrink its loan book. In a falling market, the cost of the first option is higher than that of the latter. Cutting back credit, though cost effective from the viewpoint of the bank, imposes an externality on its borrowing counterparties that are left struggling for liquidity. In such scenario, though the posting of collateral will have fulfilled its role in protecting the bank's creditors against counterparty risk, it will have contributed to spread liquidity strains throughout the financial system. If the bank's borrowing counterparties do not have enough liquid assets, they will be forced to sell their illiquid portfolio precipitously and may become insolvent. This is particularly the case of institutions that rely on money markets to secure most of their funding as observed during the recent global financial crisis. Some cases in point are the collapse of Bear Stearns, Northern Rock and Lehman Brothers, and the evaporation of entire segments of the broker-dealer industry (Chailloux, 2010). In sum, a negative shock in the trading book of an individual institution, even if temporary, may propagate as a solvency shock throughout parts of the financial system and the real economy.

While a number of papers have discussed the reinforcing effects of market risk and funding risk in creating pro-cyclical loss spirals (Adrian and Shin, 2009; Brunnermeier and Pedersen, 2009), the correlation between asset returns and funding costs in financial intermediaries' balance sheets and its role in propagating financial contagion through liquidity hoarding have received far less attention. Our paper analyzes the role and the systemic implications of the use of collateral in funding operations and suggests alternative regulatory policies to enhance the overall stability of the financial system.

The paper contributes to the literature on systemic risk in the financial system. The debate on how to identify systemically important financial institutions that require strengthened regulation intensified following the April 2, 2009 G-20 Summit in London. It has been widely recognized that the large size or inteconnectedness of a financial institution as well as common or correlated exposures across institutions all contribute to the spreading of financial instability. This definition of systemically important institutions dwells on the notion that contagion can stem from the failure (bankruptcy) of a particular institution, market or instrument (IMF, 2009). The same view underlies the CoVaR measure for systemic risk proposed by Adrian and Brunnermeier (2009) whereby the systemic importance of an institution is measured by its marginal contribution to the VaR of the financial system conditional on the institution being in distress. We argue however that systemic risk may spread even if the cash lender holds enough capital to avoid failure. In our paper the cash lender never reaches its VaR threshold. Therefore it is not forced to deleverage its balance sheet to escape insolvency. Systemic risk spreads in the form of a credit squeeze as a response to liquidity strains. This action, while avoiding a reinforcing loss spiral in the lender's trading book, leads to the bankruptcy of its borrowing counterparties. This result holds even if the loan book of the lender is fully hedged against counterparty risk. That is why a microprudential measure aiming at mitigating credit risk of the lending institution is ineffective to contain contagion across the financial system.

We take the view that an institution is systemically important if a shock to its balance sheet triggers a wave of distress spreading to other financial institutions even if the latter hold unrelated asset classes. We show that, for a given size of the financial system, systemic risk might be mitigated by reducing the number of cash borrowers connected with the lending institution.

The fact that collateralized funding has extended to a larger set of market players, particularly after the introduction of triparty repo arrangements[2], may help explain the extinction of some categories of market players observed during the recent global financial crisis.

The current initiative to apply capital surcharges on systemically important institutions proposed by the Financial Stability Board (2009) aims at reducing the probability of failure of an individual institution rather than at mitigating the systemic liquidity shortage created by liquidity hoarding. In other words, it is concerned with mitigating the negative spillovers caused by a financial institution when it dies, but not when it takes radical measures to survive. In our framework, the bank has enough capital to be solvent in all states of the world. However it may not have enough capital to avoid the spike in funding costs to lever up its balance sheet in times of distress in order to ensure a sufficient flow of credit to the economy. Likewise, recent attempts to improve liquidity risk management (FSA, 2009; BIS, 2009) focus on the reduction of maturity mismatches of the regulated institution rather than on facilitating the sustained provision of liquidity to the rest of the financial sector. However, under daily remargining practices, funding costs track asset returns overnight irrespective of the maturity of the transaction. Therefore, financial contagion may unfold in the absence of maturity mismatches. It is the threat of receiving a credit downgrade that induces the financial intermediary to deleverage its balance sheet when hit by a liquidity shock.

Some other regulatory proposals to strengthen financial stability going forward include: (i) higher capital requirements as a function of maturity mismatches (Brunnermeier et al. 2009); (ii) the creation of a mandatory liquidity charge working like a Pigouvian tax to decrease maturity mismatches (Perotti and Suarez, 2009; BIS 2009), and (iii) the application of a conservatively defined haircut to create a capital cushion and limit leverage (Chailloux, 2010; Geanakoplos, 2009; BIS, 2010). Our analysis offers a menu of risk-sensitive countercyclical standards that maps these three types of regulatory proposals. However, in a market dominated by daily repricing practices, our regulatory standards do not depend on the maturity mismatches exhibited by the lending institution. Instead, their calibration is driven by the correlation between asset returns and funding costs created by over-reliance on overnight credit-sensitive wholesale funding or collateralized term credit. Our proposed standards thus tie a financial institution's portfolio allocation (asset side) to its funding structure (liability side) so as to avoid the sudden bouts of deleveraging that exacerbate systemic risk. Concerning the regulation of haircuts, our analysis supports the imposition of a regulatory haircut at the bank level provided it is sufficiently high. Otherwise, we show that a higher margin on the regulated sector might lead to a "race to the bottom" in the margin schedules offered to the unregulated sector thus increasing overall systemic risk. Alternatively, we support the regulation of haircuts at the security level which is akin to an extension of the regulatory perimeter beyond banking institutions.

Because contagion in our model does not follow from the insolvency of the lending institution, a policy response in the form of repo lender recapitalization is off the equilibrium path. As the repo lender is hoarding liquidity, a policy response in the form of a liquidity injection to the repo lender may be more effective to avoid financial contagion provided it is more cost efficient than the balance sheet deleveraging. Or else, the borrowing counterparties affected by financial contagion may be targeted directly by lender of last resort policies to prevent fire sales of assets.

[2]The tri-party repo market has experienced tremendous growth in the past 10 years, both in the US and Europe. Over the years, third-party custodial service providers have helped further its growth by facilitating transactions that offer a parking place for large influxes of short-term cash without a long-term commitment. Also, these transactions do not require investors to incur any special infrastructure or transactional costs. The estimated collateral value of the U.S. tri-party repo market reached US$1.7 trillion in July 2010 (Federal Reserve Bank of New York).

The reminder of the paper is organized as follows. In Section II, we present some stylized facts consistent with our conjecture of unstable funding structures by showing a time-varying negative correlation between asset returns and funding costs. We also provide a stylized example of the magnitude of capital shortage from the exclusion of the correlation factor during the recent global financial crisis. In Section III we develop a simple model of financial contagion where a negative shock to the trading book of an institution triggers a cash transfer that ignites financial contagion. Section IV discusses the main results. Section V sets forth policy implications for financial regulation. Section VI presents some empirical results supporting our view of financial contagion through cost of funding strains. Section VII concludes.

II. STYLIZED FACTS

Asset returns and money market spreads are negatively correlated. We conjecture that this correlation may have turned increasingly negative over time following the spectacular growth of repo funding transactions, supported by the use of risk mitigation techniques for transactions secured by financial collateral[3], and by the over-reliance on credit-sensitive wholesale funding markets. Collateralized lending activates an automatic mechanism to track daily changes in the value of collateral and adjust margins accordingly. This imposes a *de facto* time varying cost, in terms of required collateral, irrespective of the maturity of the transaction:

$$\text{negative market shock} \Rightarrow\downarrow \text{asset quality of collateral} \Rightarrow\uparrow \text{funding costs}$$

Figure 1 plots the estimated time-varying conditional correlation from a diagonal BEKK multivariate GARCH model between the weakly logarithmic rate of return on the ABX index (BBB tranche, vintage 06-01) as a proxy for asset quality of subprime mortgage backed securities, and the weakly change in the LIBOR-OIS spread, as a proxy for funding costs in the interbank market.

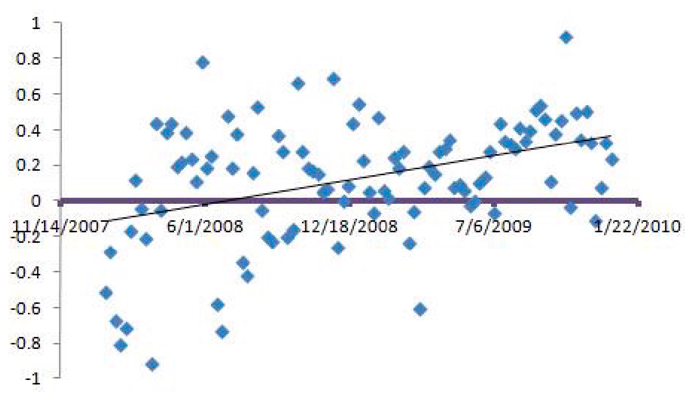

Figure 1. Correlation between ABX and LIBOR-OIS spread.

[3] Credit risk mitigation techniques under the comprehensive approach set forth by Basel II for the banking book and the trading book, allows full offset of collateral against exposures by reducing the exposure amount by the value ascribed to the collateral.

To capture the comovement of high quality collateral against funding costs, Figures 2 illustrates the 1-year rolling window correlation between the daily portfolio returns from holding Merrill Lynch Global High Grade Broad Bond Index (GBI) in USD and the daily LIBOR-OIS spread.

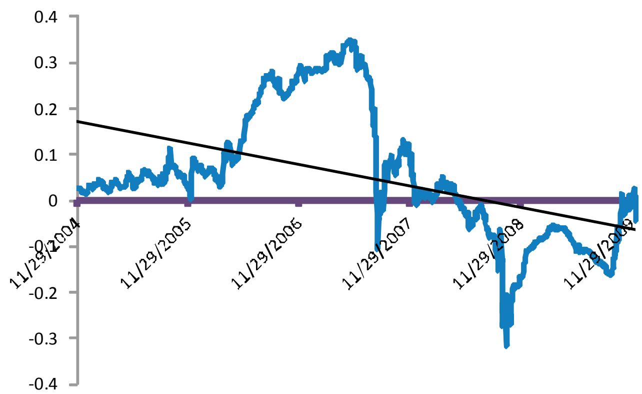

Figure 2. Correlation between GBI return and LIBOR-OIS spread.

Both figures point at a time-varying correlation pattern between asset returns and funding costs. They suggest that this correlation has turned increasingly negative over time. Note that this shows up as an increasing relationship between the CDS and the LIBOR-OIS spread in Figure 1, where asset quality is inversely correlated with its CDS quote, and as a decreasing relationship in Figure 2, where asset quality rises with the GBI index.

A concomitant question is whether liquidity shocks may destabilize repo markets to a larger extent than unsecured money markets. As it has been widely acknowledged, if margins increase with counterparty risk as implied by Table 1, liquidity shocks may create a feedback loop between market prices and margin schedules creating larger shockwaves in the repo market than in the unsecured money market. By contrast, if the uptick in counterparty risk aggravates adverse selection in interbank markets by widening the dispersion in banks' valuations, unsecured money markets may be more severely perturbed as observed during the peak of the turmoil.

	April-09	August-09
Credit risk		
LIBOR-OIS (bp)	8.05	73.24
Haircut		
US securities	0.25	3
Investment grade bonds	0-3	8-12
High-yield bonds	10-15	25-40
Equities	15	20
Senior leveraged loans	10-12	15-20
Mezzanine leveraged loar	18-25	35+
Prime MBS	2-4	10-20
ABS	3-5	50-60

Source: GFSR (April 2008) and Thomson-Reuters.

Table 1. Haircut and Credit Risk.

A. An Example of Capital Shortage under Basel II

Notwithstanding the implication of a time-varying correlation between assets returns and funding costs for solvency risk, this correlation has been ignored by microprudential regulation. For instance, Basel II regulation on capital requirements is based on an adaptation of Merton's model (1974) that assumes a stochastic nature of assets returns but assumes funding costs to be deterministic. To illustrate how the exclusion of the correlation factor may bias the minimum capital requirements needed to avert bankruptcy, consider the following example[4]. Consider a financial intermediary holding the following balance sheet:

Assets	Liabilities
safe asset d	capital K_t
risky asset P	debt D

balance sheet at $t = 0$

The rate of return of the safe asset is normalized to zero. The rate of return of the risky asset and the cost of debt are two random variables denoted by $\widetilde{x}$ and $\widetilde{r}$, respectively. Bankruptcy occurs if $y_t \leq -K_t$ where $y_t = Px - Dr$ reflects the net operating profit of the bank. Assume that y_t is distributed as a normal variable $y_t \sim N(0, \sigma_y^2)$. Suppose that the regulator sets a 99 % confidence level to avoid bankruptcy. It follows that the probability of failure: $N(-K_t/\sigma_y) \leq 1\%$ if $K_t \geq 2.33\sigma_y$ with $\sigma_y = \left(P^2\sigma_x^2 + D^2\sigma_r^2 - 2PD\sigma_{x,r}\right)^{1/2}$. To avoid failure $K_t \geq K_t^u$. Note that if the correlation between $\widetilde{x}$ and $\widetilde{r}$ is negative, i.e. $\sigma_{x,r} < 0$, the unbiased equity threshold K_t^u is greater than the biased threshold K_t^b, with the latter ignoring the correlation factor. Therefore, a capital requirement ratio that excludes the negative correlation between asset returns and funding costs underestimates the minimum capital required to maximize solvency.

To illustrate the magnitude of the capital shortage from excluding the correlation factor in the Basel II capital requirements framework, consider the following example whereby a bank holds a high quality asset in its trading book proxied by the Merril Lynch Global Bond Index (GBI) in USD. The trading book is funded in the interbank market at the 3-month LIBOR rate denominated in USD.

Under the internal model approach of Basel II's Pillar 1 framework, the capital charge to cover market risk in the trading book is based on the value at risk (VaR) methodology. The model is computed on a daily basis under a 99 percent confidence interval with a minimum 10 day holding period. The choice of the historical observation period is one year. On a daily basis, each bank must meet the following capital requirement:

$$K_t = \max\left(VaR_{t-1}, \overline{VaR}_{t,t-60} * 3\right)$$

where VaR_{t-1} denotes the previous day's VaR, and $\overline{VaR}_{t,t-60}$ stands for the average VaR on each of the preceding 60 business days augmented by a multiplicative factor of 3.

Given the comovement between GBI returns and LIBOR rate over a 10 day holding period, the capital charge based on the VaR computed from a price shock to the trading book that ignores its

[4] This example is based on an illustration of the ruin theory in the insurance industry by Plantin and Rochet (2007).

effects on the liability structure (biased VaR) will differ from that inclusive of the ripple effects from asset returns to funding costs (unbiased VaR).

For each dollar invested in the trading book, the capital shortage from applying Basel II's market risk standard is shown below.

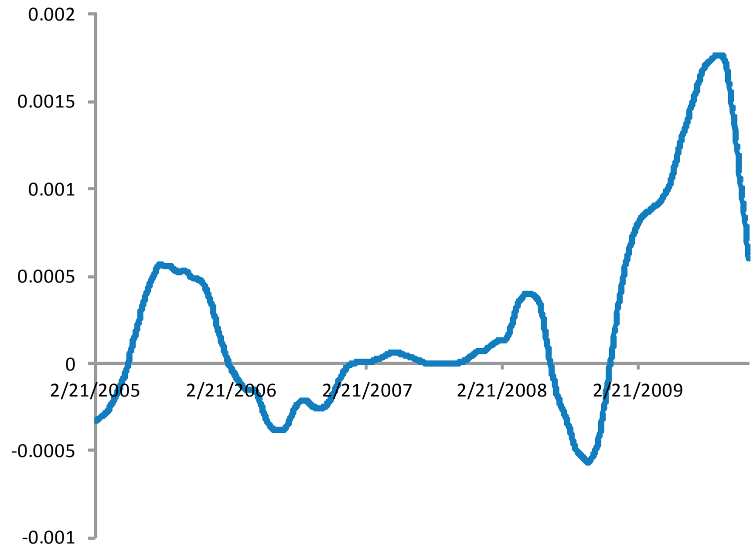

Figure 3. Underestimation of capital requirements under Basel II.

Following the 2007/08 financial crisis, the Basel II market risk framework has been revised in July 2009[5] to include a stressed VaR requirement in addition to the regular VaR. Therefore, the revised capital charge is now calculated according to the following formula:

$$K_t^r = \max\left(VaR_{t-1}, \overline{VaR}_{t,t-60} * 3\right) + \max\left(sVaR_{t-1}, \overline{sVaR}_{t,t-60} * 3\right)$$

where $sVaR_t$ denotes the stressed VaR number at t, with the model inputs are calibrated to historical data from a continuous 12-month period of significant financial stress. The regulator suggests that a 12-month period in 2007-08 would adequately reflect a period of such stress. We examine whether this enhanced capital requirement standard is affine to our computation of the VaR measure.

As a benchmark, consider the trading book holdings of Citigroup and Bank of America as of September 2009, approximately $747 billion and $520 billion, respectively[6]. Suppose that the securities portfolio is linked to the GBI index and is financed in the interbank market. The table below shows the capital shortage under Basel II against the estimated capital buffer under the revised Basel II framework, noting that to compute the stressed VaR we have used the 12-month

[5] Basel Committee on Banking Supervision, *Revisions to the Basel II market risk framework,* July 2009.

[6] These figures correspond to the lines short-term securities and investment securities reported in the balance sheet as of December 2008.

period over September 2007-2008.[7]

	Trading Book (bn $)	Capital shortage VaR_u-K (bn $)	(% equity)	Basel II revised Kr-K (bn $)	(% equity)
Citigroup	747	1.3	0.9	51.8	36.6
Bank of America	520	0.9	0.5	36.0	20.4

Sources: Bankscope; Datastream; author's calculations (September 2009).

Table 2. Illustration of capital shortage for market risk under Basel II.

The estimated capital buffer under the revised Basel II market risk framework intends to cover additional losses that may realize in periods of significant financial stress relevant to the bank's portfolio.

B. An Example of the Liquidity Risk Standards proposed by the Basel Committee

We argue that the regulatory standards proposed by the Basel Committee in December 2009 to mitigate liquidity risk may fall short from preventing the build up of systemic risk in the overall financial sector. The liquidity coverage ratio metric ensures that a bank maintains an adequate level of high quality assets that can be converted into cash to meet its liquidity needs during a 30-day period of acute liquidity stress. Suppose that a bank holds the following balance sheet:

Assets	Liabilities
trading book P_0 reverse repo d_0	capital K_0 long-term debt D_0 short-term wholesale debt d_0

balance sheet at $t = 0$

Liquidity needs are defined by the estimated net cash outflows arising in the specified stress scenario. The cash outflow is dictated by the unsecured wholesale funding run-off d_t. The cash inflow includes the contractual inflow from outstanding exposures fully performing and for which the bank has no reason to expect a default within the 30-day period. The regulator states that a bank "is expected NOT to roll-over maturing reverse repo operations secured by illiquid assets, so can assume to receive back 100% of the cash related to those agreements", that is, it will cash back d_0.

In the context of our example, this implies a net cash outflow of zero. Therefore, the bank is not required to hold high quality assets in its portfolio. However, by rolling off a repo book secured by

[7] One may wish to compare the capital buffer under the revised Basel II market risk framework with the US recapitalization scheme implemented in 200..After receiving $25 billion each under the Capital Purchase Program announced on October 13, 2008, both Citigroup and Bank of America received another $20 billion capital injection in November 2008 and January 2009, respectively (BIS Paper 48, 2009).

an illiquid portfolio, the bank may spread its liquidity strains to its repo borrowers that will be forced to unwind an illiquid portfolio at fire sales prices. This is the channel of systemic risk that we explore next.

III. THE MODEL

There are three periods: $t = 0, 1$ and 2.

There are four types of investors. Two active investors: (i) a repo-market lender (ii) N repo-market borrowers. And two passive investors: (iii) noise-traders, and (iv) a deep-pocketed outside investor.

The repo lender is a regulated institution subject to capital requirements that minimize solvency risk. We have in mind a commercial bank playing a major role in the payment system and therefore with access to both the unsecured interbank market and the secured wholesale market. By contrast, the repo borrowers are unregulated institutions. They include investment banks, hedge funds and broker dealers. As they do not play a significant role in the global payment system they lack access to the unsecured interbank market. Instead, they rely on the secured segment to cover their funding needs. Their capital base is defined by the collateral required by investors to mitigate credit risk.

The noise traders' trading decisions are subject to liquidity shocks. The deep-pocketed investor's trading decisions are governed by its degree of risk aversion.

The repo lender and the noise traders invest in a long-term asset L with fundamental value L for all t. The repo borrowers and the deep-pocketed investor have access to a long-term asset denoted by l. The fundamental value of l is l for all t.

A. The Players

1. The Repo Market Lender

At $t = 0$, the repo-market lender invests in one unit of a 2-period asset L for a cash value of P_0 by issuing a 2-period debt for an amount D_0. The lender is an active trader in the repo market where it invests its cash balances in a 1-period reverse repo operation with N repo borrowers for an individual amount of d_0. The cash balances are funded in the 1-period unsecured market (wholesale or deposits).

The unsecured debt is systemic and thus the repo lender is subject to financial regulation in the form of capital requirements. Note that any plausible liquidity requirement would be automatically satisfied given the absence of maturity mismatches in the balance sheet. The level of confidence set by the regulator is 100 percent. We shall see that systemic risk arises even when the regulator controls the risk at the local level. The analysis is robust to a lower confidence level. We normalize the risk-free rate to zero.

Assumption 1. The repo lender's long-term debt is risk-free.

The balance sheet of the repo lender at $t = 0$ looks as follows:

Assets	Liabilities
long-term asset P_0 short-term asset Nd_0	capital K_0 long-term debt D_0 short-term debt Nd_0

balance sheet at $t = 0$

The long-term asset is risky. Its price fluctuates with the trade flows initiated by noise traders in the market. To comply with the capital requirements, the repo lender needs to hold enough capital K_0 to absorb any future decline in the market price of its long-term portfolio. The long-term debt is an information-insensitive security in all states of nature, that is, debtholders are protected from the risk of adverse selection.[8] As explained by Dang et al (2009) and Gordon and Metrick (2009), to recreate an asset backed information-insensitive security the underlying asset has to be subject to a haircut as the lending rate covers the borrower's risk of default but not the adverse selection risk.[9] The repo lender posts the long-term asset as collateral with haircut $h \in (0, 1)$. At $t = 0$ the asset is valued at its fundamental value, and therefore $P_0 = L$.

2. The Noise Traders

Noise-traders are subject to liquidity shocks at $t = 1$ or $t = 2$ unrelated to the fundamental value of the asset. When hit by a liquidity shock s, noise-traders are forced to liquidate s units of the long-term asset, where $s \sim U[-\varepsilon, \varepsilon]$. The liquidated assets are purchased by other passive noise traders with the following demand function:

$$D^L(p) = \alpha(L - P_1)$$

The term α represents the liquidity of the market, that is, the ability to trade quickly without affecting the price. The term α can thus be understood as a parameter that reflects the cost of early liquidation due to imperfect market depth.

The maximum capital loss is determined by the lowest price of the long-term asset. This is reached when the noise traders have to unwind ε units of the asset following the maximum liquidity shock in their portfolio. Under the market clearing condition, the lowest feasible price of the long-term asset is thus $L - \varepsilon/\alpha$. As the asset was initially valued at its fundamental value L, the maximum capital loss is given by $\frac{\varepsilon}{\alpha}$. For the lender's debt to be risk free at $t = 0$, it must hold enough capital to absorb losses from the early liquidation of the asset by the noise traders. Also the market value of the long-term asset should be high enough to satisfy the debtholders'

[8] This implies that even if following a bad economic shock some traders produced information on the long-term risk asset while other traders did not thus creating adverse selection, the bank will be able to unwind its portfolio at $t = 2$ to get its cash back and repay its debtholders. Adverse selection may arise following a bad economic shock so that traders may fear that other traders have aquired superior information on the security and thus will only be able to trade the asset at lower prices. This is the same argument put forward to explain the adverse selection component of the bid-ask spread of an asset.

[9] Similarly, in Geanokoplos (2009), the only haircut that arises in equilibrium is the one guarantying a zero probability of default and zero interest rate even if all pairs of haircut and interest rates could in principle be traded.

haircut constraint. These two conditions determine the minimum level of capital held at time 0:

$$K_0 \geqslant \max\left(\frac{\varepsilon}{\alpha}, hP_0\right)$$

3. The Repo Market Borrowers

There are N identical investment banks with $N \geq 1$ and an outside investor. Each investment bank holds one unit of a 2-period asset denoted by l. The fundamental value of the asset is l for $t = 0, 1, 2$. We assume that the asset is valued at its fundamental value at $t = 0$, that is, $p_0 = l$. The long-term asset is financed through the rollover of a 1-period repo market transaction by pledging the underlying asset as collateral. That is, the balance sheet of the repo borrower is subject to maturity mismatch. Given the volatility in the value of the collateral, the repo lender demands a haircut $\widehat{h}$ as a protection against credit risk. The investment bank is *unregulated*. Therefore the maximum leverage $1/\widehat{h}$ is solely determined by the market haircut. The larger the haircut, the harder to finance the long term asset through repo funding. The investment bank puts down capital K_0 and raises external funds for $D_0 = p_0 - K_0$.

Assumption 2. The short-term repo funding transaction is risk-free. This restriction sets a maximum leverage for the repo borrower:

$$LEVERAGE_{\max} = \frac{1}{\widehat{h}_{\min}} = \frac{l}{l - p_1^{rf}}$$

The price of the collateral $p_1 \geq \left(1 - \widehat{h}\right) l = p_1^{rf}$ where p_1^{rf} denotes the minimum price that ensures the short-term exposure to be risk-free.

At $t = 0$ the balance sheet of a representative investment bank looks as follows:

Assets	Liabilities
risky asset p_0	capital k_0 debt d_0

balance sheet at $t = 0$

where $k_0 \geqslant \widehat{h}p_0$. We assume that the constraint is satisfied with equality. Thus $d_0 = \left(1 - \widehat{h}\right) l$.

B. The Shock

At $t = 1$, noise traders liquidate s units of the long-term asset. The market is deemed orderly and qualified for inclusion in marked to market calculations. The valuation loss is charged to income eroding the capital base of the repo lender. For the liquidity shock to spill over across markets, the repo lender must face a margin call from its creditors.

Proposition 1 Under A1-A2, financial contagion may arise if:

$$s > \max\left(0, \frac{\varepsilon - h\alpha L}{1 - h}\right)$$

Proof. Contagion can only spread across asset classes when the repo lender cuts back its lending to the repo borrower. Under A2 the short-term repo is risk-free carrying a zero risk weight in the capital requirement calculation. As the risk-free rate is normalized to zero, the impact of deleveraging in the capital requirements is zero. Under A1, the repo lender's debt is long-term and risk-free so that there are no interim payouts and thus no need for early repayment. Only if the debt contract is subject to a margin call the repo lender may have to deleverage its short-term portfolio to eliminate the transaction exposure arising from the drop in value of its long-term portfolio in asset L.

Under A1, $K_0 \geqslant \max\left(\frac{\varepsilon}{\alpha}, hP_0\right)$. First, suppose that the haircut constraint is binding, i.e. $K_0 = hP_0$. This implies that $D_0 = (1-h)\,L$. Following liquidity shock s a transaction exposure arises if $D_0 > (1-h)\left(L - \dfrac{s}{\alpha}\right)$ which is true for $s > 0$. Second, suppose that the VaR constraint is binding, i.e. $K_0 = \frac{\varepsilon}{\alpha}$. It follows that $D_0 = L - \frac{\varepsilon}{\alpha}$. A margin call is reached when $L - \frac{\varepsilon}{\alpha} > (1-h)\left(L - \dfrac{s}{\alpha}\right)$. This is equivalent to $s > \frac{\varepsilon - h\alpha L}{1-h}$. Note that, the higher the liquidity of the asset, the more likely financial contagion is triggered. When α is high, the capital buffer required to satisfy the VaR constraint is low, hence it is more likely for a given liquidity shock to violate the haircut constraint. The effect of the haircut is ambiguous. When h is high, a margin call may be triggered by a smaller liquidity shock but the initial capital buffer is also bigger. When $L > \dfrac{\varepsilon}{\alpha}$, the former effect dominates the latter.

In what follows, we assume without loss of generality that $K_0 = hP_0 = hL$. Therefore $K_1 = hL - \dfrac{s}{\alpha}$. Under the collateralized debt contract, the repo lender is obliged to satisfy the margin call by making a cash transfer or by posting equivalent securities to its debtholders. We consider both cases in turn.

IV. MAIN RESULTS

A. Margin call satisfied with cash transfer

The only accepted collateral in the collateralized debt transaction is the long-term asset. If the repo lender cannot borrow equivalent securities, the parties will reprice the debt transaction to account for the decline in value of the collateral at $t = 1$. Otherwise the debtholders will terminate unilaterally the transaction and seize the collateral.

The new purchase price under the repriced transaction is such that when multiplied by the margin ratio applicable to the original transaction it equals the market value of the securities on the repricing date. That is, the bank will transfer a cash margin C to its debtholders for $C = (1-h)\,\dfrac{s}{\alpha}$ and the purchase price under the repriced transaction will be $D_1 = (1-h)\left(L - \dfrac{s}{\alpha}\right)$. The source of liquidity to settle the cash margin is twofold.

First, it may come from the partial sale of the trading book. But given the adverse market conditions created by noise traders' liquidity shock, a further sale of securities will create a larger excess supply in the market that will cause a further price drop giving rise to a 'loss spiral' (Brunnermeier and Pedersen, 2009). Under such loss spiral, there may be no equilibrium price satisfying the margin call requested by debtholders. If we denote by γ the deleveraging of the trading book and by P_1 the ex-post price with $P_1 < L$, the margin call will be satisfied as long as:

$$(1-h)(1-\gamma) P_1 \geq (1-h) L - \gamma P_1$$

The LHS of the equation denotes the value of the remaining portfolio net of the haircut. The RHS shows the amount of collateralized debt net of the cash transfer. One may anticipate that if market liquidity is tight, excess supply of securities may depress the price to such a degree so as to violate the above inequality. Given the demand function of noise traders, P_1 is determined by:

$$P_1 = L - \frac{s+\gamma}{\alpha}$$

the margin constraint will be violated as long as: $s \geq \widehat{s}$ where $\widehat{s} = \dfrac{\alpha\gamma h}{1-(1-\gamma)h} L - \gamma$.

$\widehat{s}$ is a non-linear function of γ. It attains its maximum at $\gamma^* = \left(\dfrac{\alpha(1-h)}{h} L\right)^{1/2} - \dfrac{1-h}{h}$.

If the liquidity shock is big enough, there will be no equilibrium (γ, P_1) at which the bank can satisfy the margin constraint:

$$s \geq \frac{\alpha\gamma^* h}{1-(1-\gamma^*)h} L - \gamma^*$$

The lower the haircut and the lower the liquidity, the more likely the margin constraint will be violated.

Second, the required liquidity may be obtained from the deleveraging of the repo book. Given that the repo book is risk free, it is not subject to the loss spiral discussed above. Deleveraging the loan book is akin to a sudden stop in the rollover of the short-term repo funding to the repo borrowers. To unwind the repo transaction, they will have to sell off their asset portfolio l on the secondary market at a lower price than its fundamental value. This is the channel of *financial contagion* whereby a shock in the market for asset L transmits to the market value of asset l.

Denote by δ the deleveraging of each individual investment bank and by p_1 the price of asset l at $t = 1$. The bank's balance sheet at $t = 1$ looks as follows:

Assets	Liabilities
long-term asset $L - \frac{s}{\alpha}$	capital $hL - \frac{s}{\alpha}$
short-term asset $N\left[\left(1-\widehat{h}\right) l - \delta p_1\right]$	long-term debt $(1-h)\left(L - \frac{s}{\alpha}\right)$
	short-term debt $N\left(1-\widehat{h}\right) l$

balance sheet at $t = 1$

The deleveraging of the short-term asset opens a maturity mismatch in the balance sheet of the repo lender. Short-term liabilities exceed now the repo book by the size of the cash transfer C. This could be in principle a concern to short-term creditors. However regulatory capital requirements protect the unsecured creditors even under the most adverse shock at the time of reimbursement. Suppose that at $t = 2$ the trading book is valued at $L - \frac{\varepsilon}{\alpha}$. The proceeds from selling off the portfolio in the secondary market would be sufficient to cover both the repayment of the long-term debt $(1-h)\,L - C$ and the shortfall from unwinding the short-term asset C, given that $hL - \frac{\varepsilon}{\alpha} > 0$.

1. Marked-to-Market Accounting

The effect of the liquidity shock on the balance sheet of the investment banks at $t = 1$ depends on the accounting rule in place. If the market for the long-term asset is considered orderly and assets are valued under fair value measurement the erosion to the capital base is independent of the degree of deleveraging of the repo lender. That is:

Assets	Liabilities
risky asset $(1-\delta)\,p_1$	capital $\widehat{h}l - (l - p_1)$ debt $\left(1-\widehat{h}\right) l - \delta p_1$

balance sheet at $t = 1$

Early liquidation of the l/t asset creates excess supply by an amount:

$$s\,(p_1) = N\delta$$

We assume that there is a deep pocketed outside investor that buys the liquidated assets. The demand function of the outside investor is assumed to be:

$$d\,(p_1) = \beta\,(l - p_1)\,.$$

Here β can be interpreted as the risk-tolerance of the investor. In equilibrium:

$$N\delta = \beta\,(l - p_1)$$

The degree of deleveraging is determined by the cash transfer required by the repo lender's debtholders:

$$C = N\delta p_1 = (1-h)\,\frac{s}{\alpha}$$

subject to $0 \leq \delta \leq 1$. This implies that the market price of the risky asset is high enough, that is $p_1 \geq \frac{C}{N}$.

Proposition 2. Suppose that A1-A2 hold. Deleveraging by the repo lender yields multiple equilibria in the portfolio valuation of the repo borrower:

	Asset price	Asset deleveraging
High level equilibrium	$p_1^h = \frac{l}{2} + \lambda$	$\delta^h = \dfrac{C}{Np_1^h}$
Low level equilibrium	$p_1^l = \frac{l}{2} - \lambda$	$\delta^l = \dfrac{C}{Np_1^l}$

where $\lambda = \sqrt{\frac{l^2}{4} - \frac{C}{\beta}}$, decreases with the margin call suffered by the repo lender and the risk aversion of the deep-pocketed investor.

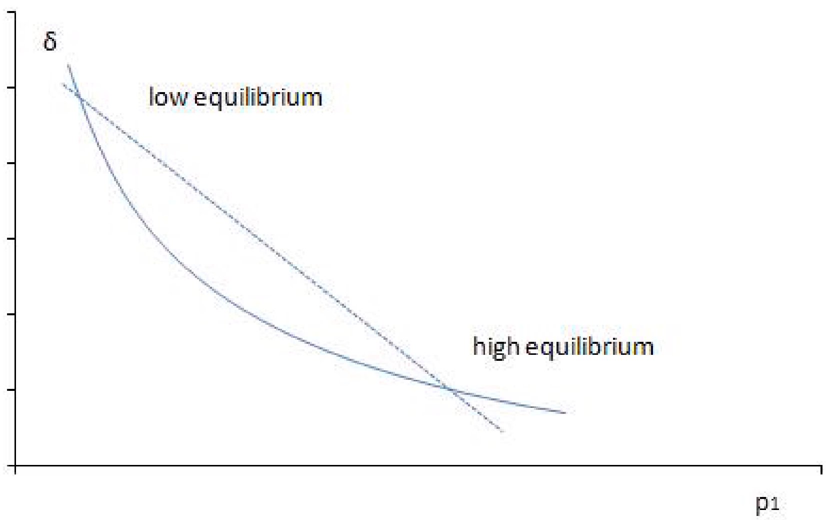

Figure 4. Multiple equilibria in asset prices.

A principle for sound margining policies recently proposed by Chailloux (2009), Geanakoplos (2009), and the Committee of the Global Financial System (2010) is the setting of conventional haircuts for little-traded and difficult to price repo collateral. The following result shows however that the efficacy of this policy to reduce systemic risk depends on whether it is applied across all financial institutions. If it is only the regulated segment that is subject to a higher margins, we might observe in equilibrium a decline in the haircut required to the repo borrower, following competitive pressures, as a lower haircut in the repo transaction would still guarantee a risk-free loan. This would however increase the leverage of the unregulated segment, increasing the overall risk of the financial system. This result is contained in the following corollary.

Corollary 1. Suppose that A1-A2 hold and the high-level equilibrium prevails. The maximum leverage of the repo borrower raises with the haircut schedule imposed on the repo lender.

Proof. Replace $\widehat{h}_{\min}$ by the minimum price for the long-term asset under the high level equilibrium at $t = 1$, evaluated at the maximum cash margin that might be requested by the repo lender's creditors if the maximum liquidity shock materializes, that is, $s = \varepsilon$.

$$LEVERAGE_{\max} = \frac{1}{\frac{1}{2} - \left(\frac{1}{4} - \frac{(1-h)\varepsilon}{\alpha\beta l^2}\right)^{1/2}}$$

It follows that the repo borrower's maximum leverage is an increasing function of h.

The intuition is that a higher margin on the repo lender limits the maximum cash transfer that may be solicited by its creditors thus pushing up the minimum feasible price of asset l following balance sheet deleveraging. This allows the repo lender to lower the haircut on the collateral posted by the repo borrower and still ensure a risk-free repo transaction.

Bankruptcy of Repo Borrowers Following the partial deleveraging of asset l triggered by the liquidity shock in the market for asset L, repo borrowers will survive as a going concern provided they are able to rollover the funding of their remaining portfolio. To rollover their repo facility at $t = 1$, repo borrowers' capital base has to be large enough to satisfy the haircut constraint required by the repo lender:

$$\widehat{h}l - (l - p_1) \geq \widehat{h}\,(1 - \delta)\, p_1$$

This requires the price of the long-term asset l to be high enough at $t = 1$:

$$p_1 \geq l - \frac{\widehat{h}}{1 - \widehat{h}} \frac{C}{N} = p_1^s$$

where p_1^s denotes the minimum price that guarantees survival of the repo borrower. Note that the price of the risky asset at $t = 1$ may be too low to ensure the rollover of short-term funding under the repo funding agreement while being high enough for the credit exposure to be risk free from the viewpoint of the lender. Under this scenario, the repo lender will seize the posted collateral prompting the liquidation of the repo borrower.

Proposition 3. Assume that A1-A2 hold. Under marked-to-market accounting, a liquidity shock s in asset L, will lead to the bankruptcy of the cash borrower for intermediate values of the haircut schedule:

$$\frac{1}{2} - \frac{\lambda}{l} < \widehat{h} < \frac{1}{1 + \dfrac{C}{N(\frac{l}{2} - \lambda)}}$$

where the latter inequality follows from substituting p_1 for its equilibrium value. The haircut schedule has to be sufficiently high to shield the repo lender from a drop in the value of the collateral making the transaction risk-free as implied by A2. But if the haircut is not high enough it will allow the cash borrower to leverage its market position making it more vulnerable to a liquidity shock that may precipitate its failure.

In what follows we endogenize the haircut on the collateral posted by the repo borrower. Suppose that the haircut is determined so as to satisfy Assumption 2 with equality under the high equilibrium. That is:

$$p_1^{\min} = \left(1 - \widehat{h}\right) l$$

Substituting the value of $p_1^{\min}$, we obtain the following functional schedule for the haircut requested to the repo borrower:

$$\widehat{h} = \frac{1}{2} - \left(\frac{1}{4} - \frac{(1 - h)\,\varepsilon}{\alpha\beta l^2}\right)^{1/2}$$

Bankruptcy of the repo borrowers will follow when the price of asset l is too low to satisfy the collateral constraint imposed by the repo lender. This is akin to the liquidity shock s being too large:

$$s \geq \frac{\alpha}{(1-h)\lambda}\left(l - \frac{N}{\lambda\beta}\right) = \widetilde{s}$$

where $\lambda = \frac{\widehat{h}}{1-\widehat{h}}$.

The smaller the RHS of the equation, the more likely the repo borrowers may go bankrupt. Note that when interconnectedness (N) of the repo lender is large, per-capita deleveraging is low and therefore the amount to be refinanced by each cash borrower is large. But under fair value accounting, the erosion of the capital base is independent of individual deleveraging. Therefore cash borrowers may be unable to rollover the funding of their existing portfolio prompting bankruptcy.

The relationship between the haircut on the bank's collateralized debt h and the likelihood of bankruptcy of its repo counterparties $\widetilde{s}$ is driven by two opposite effects. Under the direct effect, the higher h, the lower the expected margin call suffered by the repo lender, lessening the propagation of the liquidity shock from asset L to asset l, thus cushioning its borrowing counterparties. Under the indirect effect, the higher h, the lower $\widehat{h}$ and therefore the smaller the capital buffer carried by the repo borrower. A smaller capital base undermines the resilience of the repo borrower to withstand a solvency shock thus increasing the probability of failure. The following corollary states the condition under which the latter effect dominates the former.

Corollary 2. Suppose that A1 hold and $\widehat{h}$ is set endogenously to satisfy A2 with equality. A higher haircut on the collateralized debt issued by the repo lender will increase the likelihood of bankruptcy of the repo borrowers provided the following condition is satisfied:

$$(1-h)^2 \lambda'(h) - (1-h)\alpha\lambda\left(l - \frac{N}{\lambda\beta}\right) - \alpha\beta\lambda N\lambda'(h) > 0$$

Proof. The above inequality ensures a negative relationship between $\widetilde{s}$ and h, so that bankruptcy follows for a larger set of liquidity shocks.

A Numerical Example An implication of Proposition 3 is that for a given liquidity shock the more *interconnected* the repo lender, i.e., the greater the number of counterparties in the repo market N, the more likely cash borrowers will be unable to withstand the liquidity shock.

The table below illustrates a numerical example under the following parameters:
$L = 100; l = 50; s = 0.1L; \alpha = \beta = 0.5$.

For feasible values of the haircut only the high equilibrium satisfies the minimum number of traders' constraint that ensures $\delta \leq 1$ (no short selling).

Lender	Cash transfer	High equilibrim			Low equilibrim			Borrower	p_1^{rf}	p_1^{s}				
h	C	p1	N*δ1	min N	p1	N*δ1	min N	h*		N=1	N=2	N=3	N=4	N=5
0.01	19.80	49.20	0.40	0.40	0.80	24.60	24.60	0.01	49.50	49.80	49.90	49.93	49.95	49.96
0.02	19.60	49.20	0.40	0.40	0.80	24.60	24.60	0.02	49.00	49.60	49.80	49.87	49.90	49.92
0.03	19.40	49.21	0.39	0.39	0.79	24.61	24.61	0.03	48.50	49.40	49.70	49.80	49.85	49.88
0.04	19.20	49.22	0.39	0.39	0.78	24.61	24.61	0.04	48.00	49.20	49.60	49.73	49.80	49.84
0.05	19.00	49.23	0.39	0.39	0.77	24.61	24.61	0.05	47.50	49.00	49.50	49.67	49.75	49.80
0.06	18.80	49.24	0.38	0.38	0.76	24.62	24.62	0.06	47.00	48.80	49.40	49.60	49.70	49.76
0.07	18.60	49.24	0.38	0.38	0.76	24.62	24.62	0.07	46.50	48.60	49.30	49.53	49.65	49.72
0.08	18.40	49.25	0.37	0.37	0.75	24.63	24.63	0.08	46.00	48.40	49.20	49.47	49.60	49.68
0.09	18.20	49.26	0.37	0.37	0.74	24.63	24.63	0.09	45.50	48.20	49.10	49.40	49.55	49.64
0.10	18.00	49.27	0.37	0.37	0.73	24.63	24.63	0.10	45.00	48.00	49.00	49.33	49.50	49.60
0.11	17.80	49.28	0.36	0.36	0.72	24.64	24.64	0.11	44.50	47.80	48.90	49.27	49.45	49.56
0.12	17.60	49.29	0.36	0.36	0.71	24.64	24.64	0.12	44.00	47.60	48.80	49.20	49.40	49.52
0.13	17.40	49.29	0.35	0.35	0.71	24.65	24.65	0.13	43.50	47.40	48.70	49.13	49.35	49.48
0.14	17.20	49.30	0.35	0.35	0.70	24.65	24.65	0.14	43.00	47.20	48.60	49.07	49.30	49.44
0.15	17.00	49.31	0.34	0.34	0.69	24.66	24.66	0.15	42.50	47.00	48.50	49.00	49.25	49.40
0.16	16.80	49.32	0.34	0.34	0.68	24.66	24.66	0.16	42.00	46.80	48.40	48.93	49.20	49.36
0.17	16.60	49.33	0.34	0.34	0.67	24.66	24.66	0.17	41.50	46.60	48.30	48.87	49.15	49.32
0.18	16.40	49.34	0.33	0.33	0.66	24.67	24.67	0.18	41.00	46.40	48.20	48.80	49.10	49.28
0.19	16.20	49.34	0.33	0.33	0.66	24.67	24.67	0.19	40.50	46.20	48.10	48.73	49.05	49.24

Table 3. Survival of cash borrowers as a function of leverage and interconnectedeness.

2. Marked-to-Model Accounting

Following the amendments to fair value accounting by the Financial Accounting Standards Board (FASB) in April 2009, we assume that the market for the long-term asset l is considered temporarily distressed, thus allowing firms to replace marked-to-market accounting by marked-to-model accounting whereby valuation is linked to fundamentals. The effect of this policy is to reduce the level of mark-downs thus relieving pressures on the valuation of collateral following deleveraging by the repo lender.

Under this policy, the balance sheet of the repo borrower looks as follows:

Assets	Liabilities
risky asset $(1-\delta)\,l$	capital $\widehat{h}l - \delta\,(l - p_1)$ debt $\left(1 - \widehat{h}\right) l - \delta p_1$

balance sheet at $t = 1$

The constraint that allows the repo borrower to renew its repo facility for the funding of its remaining portfolio is:

$$\widehat{h}l - \delta\,(l - p_1) \geq \widehat{h}\,(1-\delta)\,l$$

Higher deleveraging creates two effects. On the one hand, it deepens capital destruction. On the other hand, it lowers the margin required by the repo lender to continue providing repo funding. It turns out that both effect cancel each other. The likelihood of survival is thus independent of the deleveraging process and hence of the number of repo borrowers. It turns out that repo borrowers will be able to refinance their portfolio as long as A2 holds, that is, provided the transaction is risk-free. This result is summarized in the following proposition.

Proposition 4. Assume that A1-A2 hold. Under marked-to-model accounting, a liquidity shock s in asset L, will never lead to the bankruptcy of cash borrowers.

B. Margin call satisfied with equivalent margin securities

Alternatively the bank may eliminate its net exposure to its debtholders by borrowing equivalent securities and post them as additional collateral.

The bank should be able to raise unsecured debt for an amount of $B = \phi(L - \frac{s}{\alpha})$ where ϕ denotes the number of securities and $(L - \frac{s}{\alpha})$ the market price at $t = 1$. To eliminate the net open exposure, ϕ should be such that the market value of the overall posted collateral satisfies the initial haircut agreed on the initial repo transaction: $(1-h)(1+\phi)\left(L - \frac{s}{\alpha}\right) \geq (1-h)L$. This implies: $\phi \geq \frac{\frac{s}{\alpha}}{L - \frac{s}{\alpha}}$. We assume that the constraint is satisfied with equality.

The resulting balance sheet of the repo lender looks as follows:

Assets	Liabilities
long-term asset $(1+\phi)\left(L - \frac{s}{\alpha}\right)$ short-term asset $N\left(1-\widehat{h}\right)l$	capital $hL - \frac{s}{\alpha}$ long-term debt $(1-h)L$ unsecured debt $\phi(L - \frac{s}{\alpha})$ short-term debt $N\left(1-\widehat{h}\right)l$

balance sheet at $t = 1$

A moment's thought will reveal that though the initial capital requirement was enough to cover the market risk of the trading book with 100 percent confidence, it may not be enough to withstand further declines in the market value of the borrowed securities. The new creditors of the unsecured debt will require a positive interest rate in the good times to compensate for the probability of default in bad times. Creditors are patient and risk-neutral, therefore the equilibrium interest rate will guarantee the recovery of the principal on expected terms:

$$\int_{-\varepsilon}^{\widehat{s}} \phi(L - \frac{s}{\alpha})(1+r) f(s)\, ds + \int_{\widehat{s}}^{\varepsilon} \left[(1+\phi)(L - \frac{s}{\alpha}) - (1-h)L\right] f(s)\, ds = \phi(L - \frac{s}{\alpha})$$

The first term denotes the repayment of principal and interest receipts when the portfolio is subject to a positive shock $s \in [-\varepsilon, \widehat{s}]$. The second term denotes the residual value of the trading book net of repayment to secured debtholders following a negative shock $s \in [\widehat{s}, \varepsilon]$.

Solving the above equation and noting that the valuation of the portfolio at the cutoff point $\widehat{s}$ is just enough to cover both the collateralized debt and the unsecured debt inclusive of interest payments, the following two equations jointly determine the equilibrium interest rate r and the cutoff value $\widehat{s}$:

$$\left[\frac{s}{\alpha}\left(1+r\right)\frac{\left(\widehat{s}+\varepsilon\right)}{2\varepsilon}\right]+\left\{\left[hL\frac{\left(\widehat{s}+\varepsilon\right)}{2\varepsilon}-\frac{\left(\varepsilon^{2}-\widehat{s}^{2}\right)}{4\varepsilon\alpha}\right]+\phi\left[L\frac{\left(\widehat{s}+\varepsilon\right)}{2\varepsilon}-\frac{\left(\varepsilon^{2}-\widehat{s}^{2}\right)}{4\varepsilon\alpha}\right]\right\}=\frac{s}{\alpha}$$

$$\left(1+\phi\right)\left(L-\frac{\widehat{s}}{\alpha}\right)=\frac{s}{\alpha}\left(1+r\right)+\left(1-h\right)L$$

The first bracket in the LHS of the first equation shows the expected recovery of the loan conditional on no default. The second bracket shows the residual value of the trading book conditional on default. The first term contains the expected value of the initial collateral net of the collateralized debt repayment. The second term shows the expected value of the additional collateral. The RHS of the equation contains the value of the unsecured debt.

The second equation shows a negative relationship between the size of the initial shock s, and the cutoff value of the shock that triggers default, $\widehat{s}$.

The next question is to examine under which conditions the bank will decide to lever up the balance sheet to satisfy the margin call rather than to deleverage by cutting back its reverse repo operations. Suppose that we begin with a situation in which the bank receives a margin call. The bank anticipates the cost associated to borrowing new securities due to the deterioration in its credit outlook. Thus, deleveraging the balance sheet would be a dominant strategy as the repo book is risk free. The problem is that although this action is optimal from the viewpoint of the bank imposes an externality in the financial sector in the form of systemic liquidity distress. The only way to stem the bank from deleveraging is to regulate the capital base ex-ante (before the liquidity shock hits) to preserve the bank's credit profile ex-post (after the negative shock hits at $t=1$). This would contain the cost of raising new unsecured debt, that the regulatory authorities have normalized to zero by setting a 100 percent confidence level.

To ensure zero probability of default, the bank should hold enough capital to repay the unsecured loan under the most severe market shock at the time of reimbursement. If we denote by K_r the needed regulatory capital, it should hold that:

$$K_{r}\geq\frac{s}{\alpha}-\left[\left(1+\phi\right)\left(L-\frac{\varepsilon}{\alpha}\right)-\left(1-h\right)L\right]\text{ for } \textit{all } s\in\left[0,\varepsilon\right]$$

where the RHS of the equation denotes the principal of the unsecured debt minus the valuation of the trading book evaluated under the most severe shock ε net of the repayment of the collateralized debt.

Substituting the value of ϕ, and after simple algebra: $K_{r}\geq\frac{s}{\alpha}+\left(1-h\right)L-\frac{L\left(L-\frac{\varepsilon}{\alpha}\right)}{\left(L-\frac{s}{\alpha}\right)}$.

This means that the capital buffer in excess to the minimum capital requirement to ensure the bank's solvency is given by:

$$K_{\min}^{+}=\frac{s-\varepsilon}{\alpha}+\left(1-h\right)L-\frac{L\left(L-\frac{\varepsilon}{\alpha}\right)}{\left(L-\frac{s}{\alpha}\right)}\text{ for } \textit{all } s\in\left[0,\varepsilon\right]$$

It is interesting to note that not only the risk profile of the portfolio matters for credit risk but also the sequencing of shocks. A larger shock at $t = 1$ implies higher leverage, as the value of new debt $B = \frac{s}{\alpha}$ increases with s, thus pushing up the bank's credit risk as the cutoff value triggering default $\widehat{s}$ declines with s. Thus, both leverage and credit risk increase with the magnitude of the initial shock. This may lead to the conclusion that the required capital buffer $K^+_{\min}$ is highest when the shock s attains its maximum value ε. This intuition is however mistaken due to the following countervailing effects. On the one hand, a larger shock s raises the bank's leverage. On the other hand, the number of securities borrowed at $t = 1$, ϕ, increases. This offers additional protection to unsecured borrowers as the pool of collateral is now larger whereas the secured debt remains fixed at $(1 - h)\, L$. It turns out that the minimum capital buffer is a non-monotonic function of the magnitude of the initial shock s :

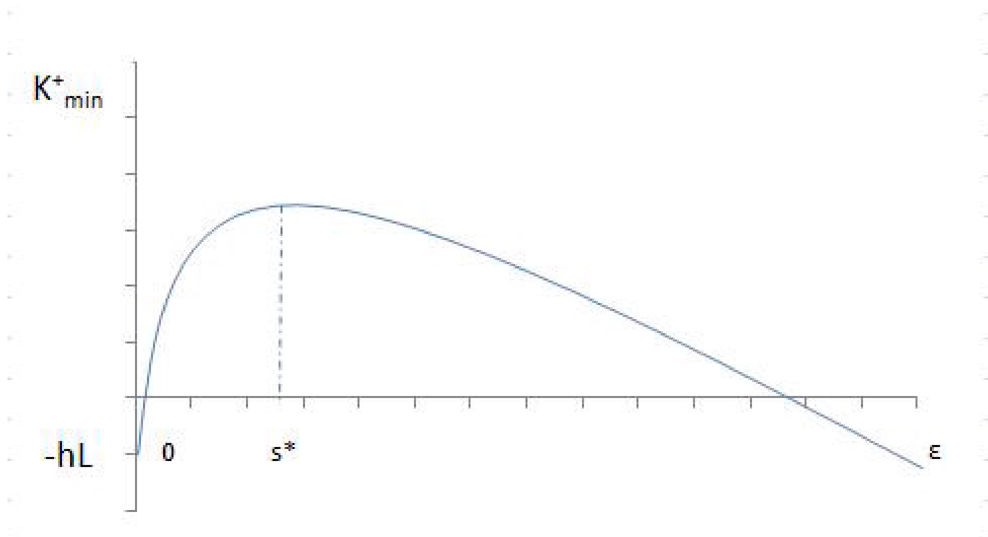

Figure 5. Capital buffer and liquidity shock.

At $s^* = \alpha \left[L - \sqrt{L\left(L - \frac{\varepsilon}{\alpha}\right)} \right]$, $\left.\frac{dK^+_{\min}}{ds}\right|_{s^*} = \frac{1}{\alpha}\left(1 - \frac{L\left(L - \frac{\varepsilon}{\alpha}\right)}{(L - \frac{s^*}{\alpha})^2}\right) = 0$, with $\left.\frac{d^2K^+_{\min}}{ds^2}\right|_{s^*} = -\frac{2}{\alpha^2\left[L\left(L-\frac{\varepsilon}{\alpha}\right)\right]^{1/2}} < 0$. Therefore the largest minimum capital buffer is attained at s^*.

Note that the capital buffer needed to cover the largest shock ε is the same as if no liquidity shock had realized as $K^+_{\min}(\varepsilon) = K^+_{\min}(0) = -hL$.

The following graph shows the payoff profile of unsecured creditors at maturity. Their payoff is a non-linear function of the initial shock s realized at t=1 (Figure 5). The realized payoff at t=2 fluctuates with the value of the underlying portfolio at t=2 (Figure 6). For a given liquidity shock s at t=1:

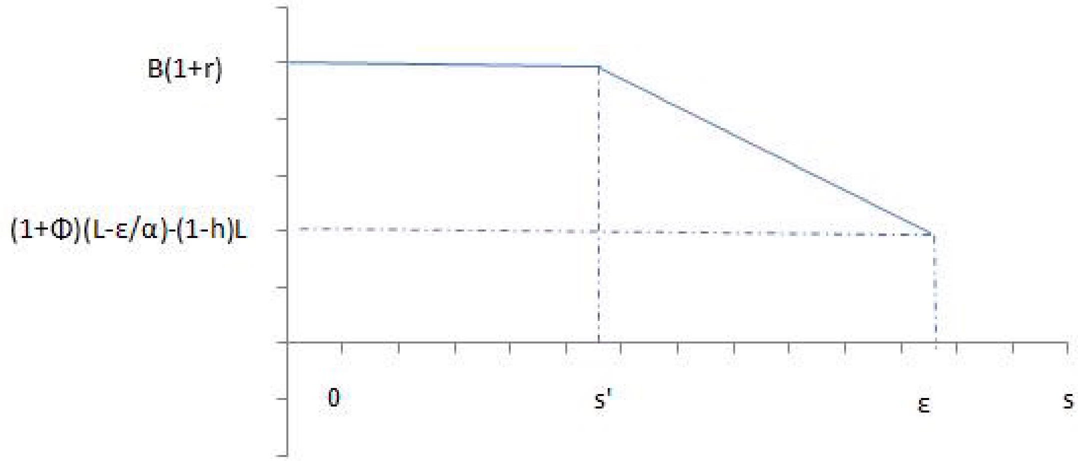

Figure 6. Payoff profile of unsecured creditors.

The maximum loss given default (LGD) is computed by evaluating the payoff function at s^* and assuming that the worst shock realizes at t=2.

$$\max LGD = LGD(\varepsilon)|_{s*} = 2\left(L - \sqrt{L\left(L - \frac{\varepsilon}{\alpha}\right)}\right) - hL$$

An interesting question is the role played by the haircut on the protection of unsecured creditors. One may think that a higher haircut on collateralized debt makes the bank more vulnerable to changes in the value of the posted collateral as it may be forced to borrow more securities to satisfy the margin ratio. Higher leverage would then contribute to an increase in its credit risk. It turns out however that a higher haircut on collateralized debt serves not only to protect the secured debtholders but also the unsecured creditors. The reason is that the number of borrowed securities is inelastic to the level of the haircut whereas the repayment of the collateralized debt from the same pool of collateral decreases with the level of the haircut.

The minimum capital buffer $K^+_{\min}$ increases with the variance of the liquidity shock $\sigma_s^2 = \dfrac{\varepsilon^2}{3}$ and decreases with the level of the haircut h. Riskier portfolios would require a higher capital buffer. For a given portfolio risk, capital buffers would be countercyclical as they would increase in good times (associated with low haircuts) and decline in bad times (when haircuts are higher).

V. IMPLICATIONS FOR MACROPRUDENTIAL REGULATION

To prevent the spread of liquidity risk through the deleveraging of the repo book, the regulatory authority has three options.

First, to impose a liquidity ratio. Part of the initial capital would be invested in liquid securities that will be drawn to settle any future cash margin that may follow from a market shock to the bank's trading book. By definition, liquid securities are not subject to liquidity risk[10] and thus, are not prone to loss spirals. The size of the liquidity buffer would be determined by the largest liquidity shock that could trigger a margin call:

$$L_r^+ = (1-h)\,\frac{\varepsilon}{\alpha}$$

The liquidity buffer would rise with the illiquidity of the trading book and the volatility of the liquidity shock. Also it would be inversely correlated with the prevailing market haircut.

Second, to strengthen the initial capital base so as to avoid a credit downgrade of the bank following a negative shock at $t = 1$. This would allow the bank to borrow equivalent securities at the risk-free interest rate normalized to zero. The additional regulatory capital would be computed by evaluating the capital buffer at the shock inducing the highest probability of default at $t = 1$:

$$K_r^+ = K_{\min}^+(s^*) = 2\left[L - \sqrt{L\left(L - \frac{\varepsilon}{\alpha}\right)}\right] - hL - \frac{\varepsilon}{\alpha}$$

Third, to regulate the market haircut on collateralized debt. Note that this policy is akin to require a stronger capital buffer. From the above equation, if $h \geq 2\left(1 - \sqrt{1 - \frac{\varepsilon}{\alpha L}}\right) - \frac{\varepsilon}{\alpha L}$, the capital buffer needed to sustain the credit rating of the bank would be negative and thus additional unsecured debt could be raised at no additional cost at $t = 1$. The level of the regulatory haircut is given by:

$$h_r = 2\left(1 - \sqrt{1 - \frac{\varepsilon}{\alpha L}}\right) - \frac{\varepsilon}{\alpha L}$$

The following proposition summarizes these three proposals.

Proposition 5. Assume that A1-A2 hold. Any of the following macroprudential policies can help contain the spread of systemic liquidity risk:

(i) A liquidity buffer $L_r^+ = (1-h)\,\frac{\varepsilon}{\alpha}$;

(ii) A capital buffer $K_r^+ = 2\left[L - \sqrt{L\left(L + \frac{\varepsilon}{\alpha}\right)}\right] - hL - \frac{\varepsilon}{\alpha}$;

(iii) A regulatory haircut $h_r = 2\left(1 - \sqrt{1 - \frac{\varepsilon}{\alpha L}}\right) - \frac{\varepsilon}{\alpha L}$.

The first two policies constrain the asset portfolio and the capital structure at the bank level. They are countercyclical as they move negatively with the haircut cycle. The last policy regulates the market haircut at the security level. It increases with the risk of the portfolio. This latter prescription is in line with Geanakoplos (2009).

[10] Liquidity risk is defined as a the probability of a shortfall between the value of the collateral and the exposure.

These enhanced macroprudential policies would act at the aggregate level of the financial sector to prevent liquidity strains from threatening the stability of the system. They would complement the microprudential policies dictated by solvency concerns at the individual level of the regulated segment.

VI. SUPPORTING EMPIRICAL EVIDENCE

This section provides supporting evidence to our claim that financial contagion, defined as the comovement of unrelated asset classes, is transmitted through the funding channel. We posit that a market shock to the securities held in the trading book of a cash lender increases its counterparty risk, leading to the deleveraging of its loan book. This tightens the borrowing constraint of the cash borrower, pushing up funding costs, and leading to the deleveraging of its trading book and causing a drop in the asset price of its portfolio. This section tests the causality pattern of financial contagion and examines the adjustment of asset prices and funding costs to market shocks.

A. Data

We analyze financial contagion during the global financial crisis of 2007-2009. It has been widely acknowledged that the onset of the crisis was triggered by a setback to asset prices in the U.S. real estate market that added money market pressure in advanced economies, transmitting financial distress to bond markets in emerging economies.[11]

Financial strains in the U.S. housing market were first observed in the subprime-related ABX index starting in February 2007, spreading rapidly to the mortgage lender sector and leading to the filing for bankruptcy of the major U.S. mortgage lender American Home Mortgage Investment Corp. in July 2007. To capture market developments in the real estate market we focus on the FTSE NAREIT Real Estate 50 Index (HEI) provided by the National Association Real Estate Investment Trusts. This index includes the 50 largest publicly traded real estate investment trusts and companies listed on the NYSE, AMEX or NASDAQ.

To analyze the transmission of spillovers to an asset class unrelated to the US real estate market, we consider the Merrill Lynch USD emerging corporate global index (EMI) that covers investment grade corporate bonds issued in emerging market countries.

As a measure of money market funding stress in the unsecured interbank market, we use the spread between the 3-month LIBOR and the overnight index swap rate (spread). The high correlation between the LIBOR-OIS spread and the repo rate in 2007-08 (Table 4) points at the comovement between the funding constraint faced by the repo lender in the unsecured market and the tightening of credit faced by the repo borrower in the secured market (supported by high

[11] A recent paper that examines financial spillovers to emerging markets during the global financial crisis is Frank and Hesse (2009).

grade collateral).

	First half 2007	Second half 2007	2007	2008
LIBOR-OIS spread (bp)	8.03	56.79	32.41	107.05
Repo rate spread (bp)	0.16	58.56	29.71	130.03
AA-AAA Corporates	-1.69	55.27	27.13	123.86
BBB+/A Corporates	2.01	61.85	32.28	136.19
Correlation: 99.9%				

Source: Gorton and Metrick (2009) and Datastream.

Table 4. Repo rates and LIBOR-OIS spread.

Our sample period runs from 1/18/2005 to 12/15/2009, with the start date being dictated by the availability of the EMI variable. We obtain the weekly data from Datastream. Table 4 reports the summary statistics for the three variables used in this section.

	HEI	SPREAD (bp)	EMI
Mean	209.22	41.78	221.445
Median	220.10	10.93	225.17
Maximum	314.31	341.10	270.92
Minimum	83.00	-0.06	154.33
Std. Dev.	55.67	53.40	25.87
Skewness	-0.52	2.40	-0.65
Kurtosis	2.41	10.46	3.15
Jarque-Bera	15.33	841.40	18.60
Probability	0.00	0.00	0.00
Sum	53769.65	10738.34	56911.23
Sum Sq. Dev.	793516.60	729945.20	171271.20
Observations	257	257	257

Table 5. Summary Statistics of Emerging Corporate Global Index.

B. Methodology

We specify a structural vector autoregressive model (SVAR) of asset prices (HEI and EMI) and funding costs (SPREAD) whereby each variable is expressed as a function of its own lags as well as the lags of all the other variables in the system. We include two lags in the system as suggested by the VEC lag exclusion Wald test for both lags at the 5 percent confidence level. A SVAR is a dynamic structural model with the following specification:

$$B_0 y_t = \sum_{i=1}^{2} B_i y_{t-i} + u_t$$

where $y_t = (HEI_t, SPREAD_t, EMI_t)^T$, B_0 and B_i represent the contemporaneous and lagged interactions amongst the variables, respectively, and u_t is a $(3x1)$ vector that includes the structural shocks to the U.S. real estate market, the interbank market and the emerging countries' bond market.

To validate our conjecture on the sequencing of financial contagion from distress in the U.S. real estate market to strains in wholesale funding to dislocation of emerging economies' bond markets, we conduct the Granger causality test in the series of the three variables. The results are shown below.

VEC Granger Causality
Block Exogeneity Wald Tests
Sample: 1/18/2005 12/15/2009
Included observations: 254

Excluded	Chi-sq	df	Prob.
Dependent variable: D(HEI)			
D(SPREAD)	3.7850	2	0.1507
D(EMI)	3.0482	2	0.2178
All	6.8078	4	0.1464
Dependent variable: D(SPREAD)			
D(HEI)	12.2282	2	0.0022
D(EMI)	2.4550	2	0.2930
All	14.8780	4	0.0050
Dependent variable: D(EMI)			
D(HEI)	35.5106	2	0.0000
D(SPREAD)	67.2760	2	0.0000
All	107.6119	4	0.0000

Table 6. Granger Causality Test of Financial Contagion.

The Granger causality test establishes a recursive structure in the dynamic system of equations at the 1 percent confidence level. This implies that the contemporaneous matrix B_0 is lower triangular, i.e. $B_0 = \begin{pmatrix} \beta_{1,1} & 0 & 0 \\ \beta_{2,1} & \beta_{2,2} & 0 \\ \beta_{3,1} & \beta_{3,2} & \beta_{3,3} \end{pmatrix}$.

The recursive structure on the short-run parameters of the model imposes the following short-run ordering on the variables:

$$HEI \Rightarrow SPREAD \Rightarrow EMI$$

whereby a shock to the real estate market instantaneously feeds into the other two variables without any contemporaneous feedback. There is however feedback in future points in time. The triangular ordering allows a structural identification of the impulse responses to economic shocks whereby a Choleski decomposition can be performed using a sequence of OLS regressions. Moreover, the parameters are asymptotically efficient.

C. Results

The effects of alternative shocks on the dynamic patterns of the key variables in the model are highlighted using dynamic impulse response functions with one standard deviation coefficients given by the dashed lines.

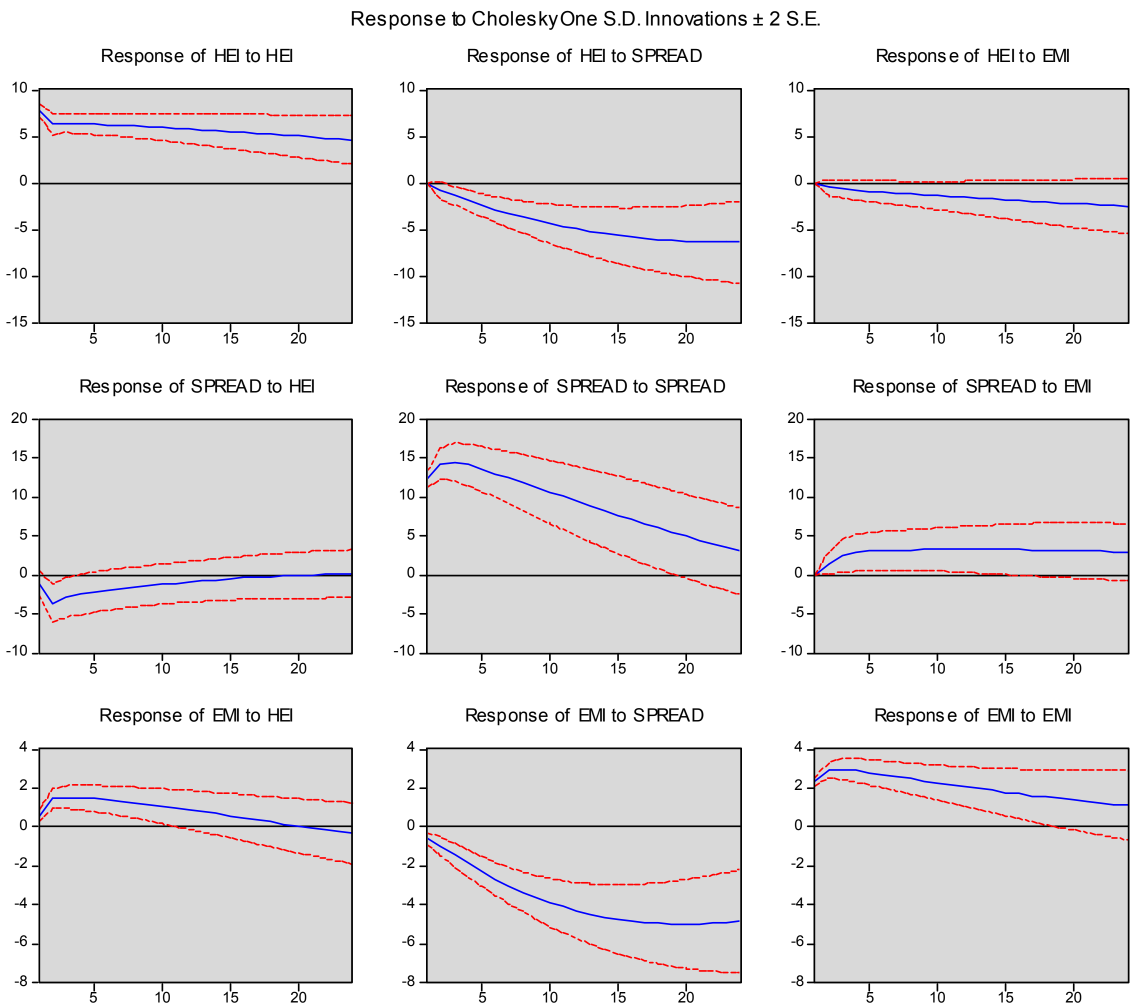

Figure 7. Dynamic Impulse Response to Structural Shocks.

The effects of a positive shock to the US housing market on all three variables is given in the first column of graphs of Figure 7. A shock to the US housing market leads to a simultaneous increase in the real estate equity index and a decrease in the LIBOR-OIS spread. The emerging market bond index reacts positively to the real estate shock through positive portfolio wealth effects or through a decline in risk aversion. There is a further stimulus in the short run from the drop in funding costs that dying out after five months.

A liquidity shock in the interbank market is represented in the second column of graphs of Figure 7. The effect of the liquidity shock in funding costs is highest two weeks after the initial shock and decreases gradually for over four months after which it turns negative entering into an oscillatory decaying response. This pattern is inversely mirrored by the response of emerging market asset prices. The emerging market bond index reaches its trough five months after the shock to the interbank market before rebounding back towards the initial level.

The implication of an asset price shock in emerging markets is highlighted by the third column of Figure 7. The surge in asset prices stimulate the bond price index reaching its peak two weeks after the shock and gradually slowing down for over 10 months after which there is a slight rebound in asset prices with the magnitude of this effect dissipating over time.

The dynamic properties of the SVAR are captured by the variance decomposition of the estimated model. Table 7 shows that though financial strains in the money markets do not impact upon the real estate equity index in the short run, the effects are substantial, just below 50 percent after one year. This result is consistent with the liquidity spirals set forth by Brunnermeier and Pedersen (2009).

The main determinant of LIBOR spreads is shocks in the interbank market. The effects of emerging markets' portfolio shocks initially are very small (0.59 percent in the second week) but grow gradually in importance to just over 12 percent within a year.

Despite the small impact of financing constraints as a determinant of emerging bond markets in the very short run (6 percent), they become the dominant determinant of asset prices in emerging markets in the long run explaining over 3/4 of total variation.

		Shocks		
Variable	Week	HEI	SPREAD	EMI
HEI	1	100.00	0.00	0.00
	2	99.09	0.66	0.25
	3	97.77	1.76	0.47
	4	96.06	3.27	0.67
	24	56.10	39.27	4.63
	52	42.48	46.12	11.39
SPREAD	1	0.76	99.24	0.00
	2	3.81	95.59	0.59
	3	3.76	94.86	1.38
	4	3.55	94.44	2.01
	24	1.93	89.58	8.50
	52	1.89	85.75	12.35
EMI	1	5.44	6.02	88.54
	2	14.04	7.76	78.20
	3	15.54	11.32	73.14
	4	15.69	15.67	68.63
	24	4.00	75.25	20.75
	52	9.14	76.73	14.13

Table 7. Variance decomposition for alternative shocks (in percent).

The three variables are non-stationary as their mean and variance are time variant. The augmented Dickey-Fuller unit root test indicates that they are integrated of order one. The Johansen cointegration test below indicates that the three variables are stationary through a linear combination of the series. This linear combination represents the long-run dynamics of the model as the variables do not drift too far apart from each other in the long run.

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.082717	21.93004	21.13162	0.0386
At most 1	0.021413	5.497935	14.2646	0.6781
At most 2	2.35E-06	0.000598	3.841466	0.9822

Table 8. Johansen cointegration test.

The vector error correction estimation yields the following long-run equilibrium of the model (test statistics in brackets):

$$HEI_t = \begin{array}{llll} -242.61 & -1.93 * SPREAD_t & +0.22 * EMI_t & +\widehat{\varepsilon}_t \\ & [5.16] & [-0.32] & \end{array}$$

We estimate the short-run dynamics that allow the process to adjust back to the long-run equilibrium following a disturbance. The results are contained in Table 9.

Error Correction:	D(HEI)	D(SPREAD)	D(EMI)
CointEq1	-0.021927	-0.017084	-0.005433
	[-3.34333]	[-1.67669]	[-2.96899]
D(HEI(-1))	-0.147506	-0.300139	0.104171
	[-2.30693]	[-3.02153]	[5.83949]
D(HEI(-2))	0.044181	0.105982	0.003667
	[0.65640]	[1.01355]	[0.19526]
D(SPREAD(-1))	-0.026875	0.198315	0.001445
	[-0.65769]	[3.12398]	[0.12673]
D(SPREAD(-2))	-0.065078	0.285048	-0.088497
	[-1.64983]	[4.65156]	[-8.04151]
D(EMI(-1))	-0.344369	0.453742	0.208476
	[-1.62436]	[1.37768]	[3.52468]
D(EMI(-2))	0.227517	0.082266	0.148052
	[1.12913]	[0.26280]	[2.63359]
C	-0.076457	-0.185099	0.20399
	[-0.15589]	[-0.24294]	[1.49082]
R-squared	0.116391	0.182636	0.537032
Adj. R-squared	0.091248	0.159378	0.523858
Sum sq. resids	14693.3	35461.79	1143.692
S.E. equation	7.728444	12.0064	2.15619
F-statistic	4.629105	7.852517	40.76486

Table 9. Short-run dynamics in the VECM.

We test whether the error correction term does not appear in the SPREAD equation in the VECM. The p-value is 0.13, hence fail to reject the null hypothesis that the SPREAD is weakly exogenous at the 5 percent. The strong exogeneity test however indicates that it is not strongly exogenous, so that it reacts to shocks in the real estate equity index as conjectured in our model. On the other hand, the emerging markets' bond index is endogenous to the model so that it adjusts back to the long-run equilibrium following a shock in the real estate market.

VII. CONCLUDING REMARKS

The objective of macroprudential regulation is to impose preventive and remedial policies to mitigate systemic risk. This paper has illustrated the shortcomings of a regulatory approach which sets capital and liquidity requirements to minimize the solvency risk of an individual lending institution. Even if the solvency of the lending institution is preserved, its borrowing counterparties may become insolvent as long as regulatory standards fail to account for the correlation between asset returns and funding costs. We show that when hit by a temporary liquidity shock to its trading book, a repo lender finds it cost-efficient to deleverage its maturing reverse repo agreements. As these transactions are secured by illiquid assets, deleveraging causes a wave of financial distress along a chain of market players. Repo borrowers, facing tightened credit conditions, are forced to sell part of their illiquid trading book at a loss. In this context, a temporary liquidity shock can morph into a solvency shock even if the individual lender is solvent in all states of nature as he is protected by an endogenous haircut set to free the repo transaction from credit risk.

Crucially, the probability of bankruptcy of the borrowing counterparties depends on the accounting framework in place. Under fair value accounting we showed that, for a given size of the financial system, the probability of bankruptcy increases with the interconnectedness of the repo lender. This result differs from Adrian and Brunnermeier (2009) who argue that, if a large institution is split into n identical clones, systemic risk in the market is unchanged. Our result also challenges the view that a single institution is more systemic that n identical clones, often held by systemic risk regulators (Whelan, 2010). However our claim is consistent with the widely held notion that interconnectedness increases systemic risk, although the transmission mechanism laid out in the paper differs from the one highlighted in the literature. While other authors have emphasized the systemic role played by the bankruptcy cascades created by credit interlinkages within a network, we showed that interconnectedness can increase systemic risk even if the borrowing counterparties are not interrelated and the lender remains solvent. The externality underlined in the paper is created through the effect of fair value accounting on the post-deleveraging refinancing needs of each borrower. Whereas a borrower's capital losses depend only on the aggregate size of the liquidated market portfolio, his refinancing needs increase with the number of traders selling at fire-sale prices. As under a repo agreement creditors can prompt the borrower's bankruptcy if he fails to refinance its maturing operations, the probability of insolvency raises with interconnectedness.

By contrast, we showed that under marked-to-model accounting a temporary liquidity shock will never lead to insolvency. As only realized losses through fire-sales show up in the income statement, a larger-scale deleveraging by the individual lender will shrink further his capital base. But at the same time his refinancing needs will be smaller. It turns out that these two effects offset each other. Therefore, this accounting treatment enables the repo borrower to always refinance his maturing repo operations for any given liquidity shock.

We provided supporting empirical evidence that financial contagion across unrelated asset classes is transmitted through the financing channel. Our findings suggest that the fall in bond prices experienced by emerging markets in 2007-09 was Granger-caused by liquidity strains in the US interbank market that reacted to declining prices in the U.S. real estate market.

To switch off the channel of financial contagion highlighted in the paper, we lay out a menu of alternative regulatory policies. All these measures tie the portfolio allocation of the individual lender to its funding structure.

First, the regulator could require that the lender hold enough liquid securities to prevent liquidity hoarding in the wake of market shocks to its trading book. The Basel Committee proposal of a Liquidity Coverage Ratio would require such a liquid assets buffer based on assumptions of asset liquidity and funding run-offs during a hypothetical 30-day stress scenario. However under the explicit provisions laid out by the new proposal, when considering its available cash inflows the bank should assume that all maturing reverse repurchase agreements secured by illiquid assets will not be rolled-over and thus will not have to be covered by the liquidity ratio. But it is precisely this non-rollover action that triggers the wave of systemic distress in our model. A policy implication of the paper is thus to change this particular provision to achieve better systemic risk protection. By contrast to the Net Stable Funding Ratio proposed by the Basel Committee, our liquidity measure is not a function of the maturity mismatch of the lender's balance sheet, since under collateralized lending systemic risk can spread even in the absence of maturity mismatches. Given daily remargining practices, the need for liquidity arising from a margin call does not depend on the maturity of the transaction. Instead, our liquidity cushion increases with the illiquidity of the trading book and the volatility of liquidity shocks, and declines with the market haircut. As market haircuts are procyclical, our buffer displays countercyclical features.

Second, the lender could be subject to a capital buffer requirement that would diminish the increase in funding costs to lever up the balance sheet in times of stress. This would dampen the credit squeeze caused by liquidity hoarding that lies at the heart of financial contagion. Though the recent revision to Basel II introducing a stressed value-at-risk requirement into the capital computation creates a capital cushion, this is calibrated to minimize the likelihood of bankruptcy rather than to discourage liquidity hoarding. But the paper shows that financial contagion may happen even when the cash lender is shielded away from the risk of insolvency. That is why a capital buffer focused solely on buttressing the lender's solvency may fall short of containing systemic risk.

Third, the regulator may impose a regulatory haircut which would increase with the risk of the security. Provided adequate risk management capabilities are in place, this policy would provide a more stable haircut schedule over the business cycle (Committee on the Global Financial System, 2010). The paper highlights the importance of calibrating properly the haircut at the bank level. We show that, when the repo lender issues collateralized debt, an inadequate increase in the haircut on its posted collateral may cause a surge in systemic risk in equilibrium. The reason is that the lender, now protected by a larger capital cushion, is willing to accept a lower haircut from its unregulated repo borrowers. Yet a smaller capital buffer carried by the repo borrowers undermines their resilience to withstand a solvency shock prompting their bankruptcy. This is an illustration of the 'race to the bottom' in risk mitigation measures that was observed during the global financial crisis. Only if the regulated haircut is sufficiently large to prevent any future margin call, regulating leverage at the bank level may help mitigate systemic risk. Alternatively, systemic risk can be mitigated by regulating the haircut at the security level as advocated by Geanakoplos (2009). This policy is equivalent to regulating the haircut at the institution level under a wider regulatory perimeter covering all leveraged financial intermediaries (including the shadow banking system, hedge funds, and prime brokers).

Ultimately, the optimal regulatory response will aim at minimizing the funding cost of the regulated financial sector. The resulting policy mix will be a function of the spread between the lending rate and the Treasury bill rate, the cost of equity relative to debt, and the spread between unsecured and secured funding.

With regard to remedial policies following a negative market shock, we show that injecting capital to cash lending institutions may be insufficient to avert the failure of cash borrowers. As this policy comes with a string of costly conditions, liquidity hoarding will still be the most cost-effective option available to the cash lender. Instead, policy-makers could act to support the illiquid markets hit by financial contagion in order to mitigate the capital erosion of borrowing counterparties. Alternatively, recapitalization measures should be extended to the financial intermediaries affected by financial contagion even if they lie outside of the regulatory perimeter. Whereas the first measure has been widely applied during the current financial meltdown, the second measure has been far less pervasive.

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