Systemic risk and the solvency-liquidity nexus of banks

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This version: March 28, 2014

Abstract: This paper shows the empirical interaction between solvency and liquidity risks of banks that make them particularly vulnerable to an aggregate crisis. I find that banks lose their access to short-term funding when markets expect they will be insolvent in a crisis. Conversely, a bank with more short-term debt (with a large exposure to funding liquidity risk) gets a larger capital shortfall estimate. Importantly, the short-term debt of a bank is not sensitive to the risk of the bank failing in isolation but is influenced by its solvency risk when the whole economy is under stress (measured as the expected capital shortfall in a crisis). This solvency-liquidity nexus is found to be strong under many robustness checks and to contain useful information for forecasting the short-term balance sheet of banks. The results suggest that the solvency-liquidity interaction should be accounted for when designing liquidity and capital requirements, in contrast to Basel III regulation where solvency and liquidity risks are treated separately.

Keywords: capital shortfall, funding liquidity risk, short-term funding.

JEL Classification: G01, G21, G28.

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I am extremely grateful to Viral Acharya, Luc Bauwens, Robert Engle and Christian Hafner for their excellent guidance and continuous support. I thank Stephen Figlewski, Andres Liberman, Matteo Luciani, Matthew Richardson, Sascha Steffen and David Veredas for helpful comments. I also thank Rob Capellini for providing me with V-Lab's measures of systemic risk. All remaining errors are my own.

"A more interesting approach would be to tie liquidity and capital standards together by requiring higher levels of capital for large firms unless their liquidity position is substantially stronger than minimum requirements. This approach would reflect the fact that the market perception of a given firm's position as counterparty depends upon the combination of its funding position and capital levels. [...] While there is decidedly a need for solid minimum requirements for both capital and liquidity, the relationship between the two also matters. Where a firm has little need of short-term funding to maintain its ongoing business, it is less susceptible to runs. Where, on the other hand, a firm is significantly dependent on such funding, it may need considerable common equity capital to convince market actors that it is indeed solvent. Similarly, the greater or lesser use of short-term funding helps define a firm's relative contribution to the systemic risk latent in these markets." - Remarks by Daniel K. Tarullo, Member of the Board of Governors of the Federal Reserve System, Peterson Institute for International Economics, May 3, 2013.

1 Introduction

The main function of banks is to provide liquidity by offering funding (deposits) that is more liquid than their asset holdings (Diamond and Dybvig (1983)). This liquidity mismatch, part of their business model, makes banks vulnerable to runs as creditors can demand immediate repayment when the bank faces asset shocks. The rationale for studying the solvency-liquidity nexus of banks is based on the literature explaining bank runs based on the strength of the bank's fundamentals. In Allen and Gale (1998), banking panics are related to the business cycle where creditors run if they anticipate that the bank's asset values will deteriorate. Similarly, Gorton (1988) shows that bank runs are systematic responses to the perceived risk of banks.

Theoretical models on the two-way interaction between solvency and liquidity have been more recently developed. Diamond and Rajan (2005) show that bank runs, by making banks insolvent, exacerbate aggregate liquidity shortages. In Rochet and Vives (2004), there is an intermediate range of the bank assets value for which the bank is still solvent but can fail if too many of its creditors withdraw, and the range of the interval decreases with the strength of the bank's fundamentals. Then, Morris and Shin (2008) explain that bank runs come from both the bank's weak fundamentals and the "jitteriness" of its creditors. Therefore, the failure region of the bank would be smaller if both the bank and its creditors held more cash.

An implication of this literature is that systemic risk is likely to play a key role in the solvency-liquidity nexus through the liquidation costs caused by fire sales in a crisis. If the firm fails in isolation, its illiquid assets can be liquidated for a price close to their value in best use (Shleifer and Vishny (1992)).[1] In a systemic crisis, however, potential buyers will be unable to find funding to buy the assets of the distressed firm. Creditors will consequently run from banks that are vulnerable to an aggregate shock as they anticipate these banks will not be able to repay them in a crisis.

While the solvency-liquidity nexus has been well studied theoretically in the economic literature, the interaction between solvency and liquidity risks tends to be omitted in the new capital and liquidity regulatory standards. The liquidity coverage ratio (LCR) of Basel III imposes that financial firms hold a sufficient amount of high-quality liquid assets to cover their liquidity needs over a month of stressed liquidity scenario.[2] However, the liquidity needs according to this standard are essentially a function of the funding mix of the bank and do not depend on other bank's fundamentals, in particular, on its capital adequacy and asset risks. Similarly, the required capitalization of a bank in Basel III is not related to its exposure to funding liquidity risk.[3]

The solvency-liquidity nexus of banks has also not been the center of empirical studies investigating funding liquidity risk of the financial sector.[4] In this paper, I fill this gap in the literature and test whether the solvency-liquidity nexus of banks empirically holds by examining the short-term balance sheet of 50 US bank holding companies over 2000-2013.

[1]Other fire-sale papers also relying on the Shleifer and Vishny (1992) insight include Allen and Gale (1998, 2000a,b, 2004); Acharya and Yorulmazer (2008); Acharya and Viswanathan (2011); Diamond and Rajan (2005, 2011).

[2]Next to the LCR, Basel III also introduces a Net Stable Funding Ratio (NSFR). The NSFR is the ratio of available stable funding to required stable funding over a one year horizon. The required stable funding is determined based the institution's assets and activities (Basel Committee on Banking Supervision (2011)).

[3]Funding liquidity risk is only likely to play a modest role via the interconnectedness measure used to derive the additional capital requirement for globally systemically important financial institutions (G-SIFIs). The systemic importance measure is the equally-weighted average of the size, interconnectedness, lack of substitutes for the institution's services, global activity and complexity (Basel Committee on Banking Supervision (2013b)). Interconnectedness is itself based on three indicator measures: intra-financial system assets, intra-financial system liabilities, and securities outstanding.

Alternatively, some supervisory stress test models explicitly feature funding liquidity feedbacks from the deterioration of the banks' fundamentals as in the risk assessment model for systemic institutions (RAMSI) of Aikman et al. (2009) used at the Bank of England.

[4]Related empirical studies include Das and Sy (2012) who document the trade-off between solvency and liquidity; banks with more stable funding and more liquid assets do not need as much capital to get the same stock return. Gorton and Metrick (2012) find that increases in repo rates are correlated to higher aggregate counterparty risk, whereas increases in repo haircuts are correlated to higher uncertainty about collateral values. Afonso et al. (2011) study the Fed funds market and find increased sensitivity to bank-specific counterparty risk during times of crisis (both in the amounts lent to borrowers and in the cost of overnight funds).

Short-term debt mainly consists of Fed funds purchased and repurchase agreements (repos), uninsured deposits and other short-term borrowings. Short-term assets include cash, Fed funds sold and reverse repos, and short-term debt securities.

The difference between short-term debt and short-term assets is used in this paper as a proxy for the exposure of a firm to funding liquidity risk. When liquidity conditions are tight, a financial firm faces the risk of not being able to roll-over its existing short-term debt and/or to raise new short-term debt. To survive a crisis, a firm needs a sufficient amount of liquid assets that can be converted into cash when the bank's short-term funding starts drying up. The gap between its short-term debt and short-term assets — the *liquid asset shortfall* — represents the amount of liquid assets that would be left if the bank lost its complete access to short-term funding (see Figure 1).

I test for the solvency-liquidity nexus using a fixed-effects panel vector autoregressive (VAR) model. In particular, I test for the interaction between solvency and liquidity using several measures of solvency risk: regulatory capital ratios, market measures of risk (realized volatility, expected shortfall and market beta), and a measure of the expected capital shortfall ($SRISK$) of the bank under aggregate stress defined by Acharya et al. (2010, 2012); Brownlees and Engle (2011). According to $SRISK$, a firm is adequately capitalized to survive a crisis if its ratio of market capitalization to total assets remains larger than 8% when the market index falls by 40% over the next six months. This measure is an alternative to the capital shortfall estimates of stress tests that is purely based on publicly available market data (and therefore available at a higher frequency than stress tests outcomes).

I document four important results. First, I find that the bank's capital shortfall under stress ($SRISK$) determines how much short-term debt it can raise. This result supports the models of Allen and Gale (1998); Diamond and Rajan (2005), etc. explaining bank runs based on the strength of the bank's fundamentals. Conversely, the expected capital shortfall of a bank increases when the bank holds more short-term debt (has a larger exposure to funding liquidity risk), in line with the introductory quote of D. Tarullo and some previous evidence that firms with more maturity mismatch have a larger contribution to systemic risk (Adrian and Brunnermeier (2010)). Figure 2 illustrates well the solvency-liquidity nexus where capital-constrained banks (i.e. banks with a positive $SRISK$) had a larger average exposure to liquidity risk (measured by the difference between short-term debt and short-term assets) than adequately capitalized banks until 2011. The average liquidity shortfall of capital-constrained banks reached a maximum of $133 billion in the third quarter of 2007. This exposure made them particularly vulnerable to the sudden freeze of short-term funding markets that followed.

Second, I show that not all solvency risk measures predict the short-term debt level of banks. The expected capital shortfall $SRISK$ interacts well with the level of short-term funding of the bank compared to other measures of solvency risk because (i) it is a measure of the bank's exposure to aggregate risk, and (ii) it combines both book and market values. Relating to the model of liquidation costs of Shleifer and Vishny (1992), this result suggests that a bank with higher solvency risk in isolation does not necessarily get restricted access to short-term funding. What matters most for the suppliers of short-term funding is the vulnerability of the bank to an aggregate crisis. When this crisis occurs, 'pure' solvency risk (measured by the Tier 1 leverage ratio), amplified by market shocks, explains the bank's access to short-term funding.

Third, the stressed solvency risk measure interacts with the bank's profitability (measured by its net income divided by total assets) in determining its short-term balance sheet. While a more profitable bank has a larger access to short-term funding and does not hold as much liquid assets, profitability does not have this beneficial effect on its short-term balance sheet when the bank is expected to be capital-constrained in a crisis. For example, the positive net income of \$2 billion of Citigroup in the third quarter of 2007 did not prevent the bank from losing 18% of its short-term funding (-\$172 billion) the next quarter, as Citigroup was also highly undercapitalized according to $SRISK$ (\$51 billion expected capital shortfall in 2007Q3).

Finally, out-of-sample forecasting results during the European sovereign debt crisis show that the solvency-liquidity interaction helps improve the forecasts of the short-term balance sheet of banks. Omitting $SRISK$ in the model increases the forecasting errors of the liquid asset shortfall considerably and particularly for capital-constrained banks.

Overall, the results of this paper suggest that the solvency-liquidity nexus should be accounted for when designing liquidity and capital requirements, in contrast to Basel III regulation where liquidity and solvency risks are treated separately. The paper gives empirical support to the approach advanced by Tarullo (2013) to tie liquidity and capital requirements together by requiring banks with a large exposure to short-term funding to hold an additional capital buffer. The liquid asset buffer of the LCR might be a sufficient requirement from a microprudential perspective. However, the sudden drop in short-term funding for a bank that has a perfectly maturity-matched securities book (including repos and reverse repos) may also result in fire sales and increases the risk of contagion by transferring funding liquidity risk to the bank's customers. The supplementary capital buffer is a preemptive measure that would give the confidence to creditors to continue to provide funding to the bank in a period of aggregate stress.

The rest of the paper is structured as follows. In Section 2, I describe the short-term balance sheet of banks and their solvency risk measures. I test the solvency-liquidity nexus in Section 3. I comment on the out-of-sample forecasting results in Section 4.

2 Short-term balance sheet and solvency risk measures

2.1 Long-term vs. short-term balance sheet and the liquid asset shortfall

The sample considered in this paper is a panel of 49 publicly traded US bank holding companies (BHC) reporting their regulatory accounting data over 13 years from 2000Q1 until 2013Q1 (i.e. 53 quarters). This sample of banks corresponds to the intersection between the NYU Volatility Laboratory (V-Lab) sample for its global systemic risk analysis (that will be introduced in the next section) and the bank holding companies reporting under the FR Y-9C schedule (equivalent to the Call Reports of Condition and Income of commercial banks). The names of the BHCs and their market capitalizations are reported in Appendix D.

I construct the short-term debt and short-term asset variables of these BHCs based on items extracted from their FR Y-9C reports from the SNL Financial database. The short-term debt is constituted of uninsured time deposits of remaining maturity of less than a year, securities sold under agreements to repurchase (repos), Federal funds purchased, and other borrowed money of remaining maturity of less than a year. The short-term assets include debt securities of remaining maturity of less than a year, interest-bearing bank balances (cash), securities purchased under agreements to resell (reverse repos), and Federal funds sold. The components of short-term debt and short-term assets are described and illustrated in Appendix A.

As the panel data set is unbalanced, I will restrict the following analyses to a smaller sample of 44 banks for which the time series dimension is larger than 30 observations.[5] I test the stationarity of the balance sheet quantities (in logarithms) in Appendix B using the panel unit root test robust to cross-sectional dependence of Pesaran (2007). This test indicates that the permanent impact of a shock on the size of a bank comes from shocks in

[5]This restriction excludes Goldman Sachs and Morgan Stanley from the sample as they obtained the status of bank holding company at the end of 2008.

the long-term balance sheet (where the unit root hypothesis is not rejected), whereas the short-term balance sheet shocks revert to a trend level.[6] This result is consistent with the long-term balance sheet being the core business of the traditional bank that invests insured deposits (part of the long-term debt) in loans (long-term assets).[7]

The evolution of the average balance sheet of banks is shown in Figure 3. The average size of the balance sheet (measured by total assets) triples (from $85 billion to $280 billion) over the sample period and follows an increasing trend in the long-term balance sheet. Over this period, and particularly during the financial crisis, salient events include the acquisition of out-of-sample banks by in-sample banks; Golden West Financial sold to Wachovia in May 2006, Bear Stearns sold to J.P.Morgan in March 2008, Countrywide to Bank of America in July 2008, Washington Mutual to J.P.Morgan and Merrill Lynch to Bank of America in September 2008, and the acquisition of in-sample banks by other in-sample banks; National City Corp. sold to PNC and Wachovia to Wells Fargo in the last quarter of 2008.

For the purpose of testing the solvency-liquidity nexus, this paper focuses on the short-term part of the balance sheet. The acquisition of two major investment banks (Bear Stearns and Merrill Lynch) in 2008 brought a considerable amount of short-term debt and short-term assets in the banking sector (mostly in the form of repos and reverse repos). The increase in the average short-term balance sheet is considerable with the purchase of Bear Stearns (visible on J.P.Morgan's balance sheet in 2008Q3). In comparison, the impact of the acquisition of Merrill Lynch (visible on Bank of America's balance sheet in 2009Q1) on the average short-term balance sheet is attenuated as several large banks were losing a significant amount of short-term funding at that time.

In contrast to an overall increasing trend in short-term assets, the average short-term debt slowed down in 2007Q3 with the first signs of a "run on repo" in August 2007 (Gorton and Metrick (2012)), visible on the short-term balance sheet of several large banks including Citigroup that lost $172 billion (18%) of short-term debt from 2007Q3 to 2007Q4. The average short-term debt reached a peak in the third quarter of 2008 (with the acquisition of Bear Stearns) and declined afterwards.

The gap between the short-term debt and short-term assets of a bank — its *liquid asset shortfall* — represents the amount of liquid assets that would be left if the bank lost its complete access to short-term funding.[8] The average liquidity gap of the banking sector (also

[6]The trend stationarity of the short-term balance sheet allows estimating a dynamic panel data model directly on the levels in Section 3 by applying standard estimation and inference techniques.

[7]The long-term debt (resp. assets) is the difference between total liabilities (resp. assets) and short-term debt (resp. assets).

[8]Also note that short-term assets will serve in this paper as a proxy for liquid assets due to the lack of

shown in Figure 3) was the widest at the end of 2007 making banks particularly vulnerable to the sudden freeze in short-term funding markets. The short-term funding freeze was further accentuated with credit risk concerns at the end of 2008 with Lehman Brothers' bankruptcy and the most negative average net income of banks over the sample period ($-850 million).

Since the financial crisis, the average liquid asset shortfall of banks has been declining to become negative in 2011 (i.e., banks now hold more short-term assets than short-term debt). Several circumstances explain the increase of banks' stock of short-term assets. A first explanation is linked to the persistent effect of the financial crisis on the real economy where the demand for loans has been slowly recovering and outpaced by deposit growth. As a result, banks have been investing in securities and (profitable) treasury products.[9] In order to obtain secured short-term funding, banks also need to hold more short-term liquid assets than before due to stricter collateral requirements (higher haircuts). Then, higher liquid asset holdings by banks respond to precautionary concerns by banks (protecting against anticipated interest rate increase) and the regulator. Banks are encouraged by regulation to hold more short-term liquid assets to comply with both liquidity requirements (Basel III liquidity coverage ratio) and capital requirements (as holding short-term assets usually involves low regulatory capital requirements).

2.2 Solvency risk measures

2.2.1 Regulatory capital ratios

The regulator usually employs capital ratios to assess the solvency risk of a bank. Figure 4 displays the average regulatory capital ratios: the Tier 1 common capital ratio ($T1CR$) and the Tier 1 leverage ratio ($T1LVGR$). The Tier 1 common capital ratio is the ratio of Tier 1 common equity to risk-weighted assets, whereas the Tier 1 leverage ratio is the ratio of Tier 1 capital to total assets. The upward shift in regulatory capital ratios in the fourth quarter of 2008 indicates a healthier banking system and coincides with the launch on October 14, 2008 of the Capital Purchase Program (CPP) and the Temporary Liquidity Guarantee Program (TLGP) under the Trouble Asset Relief Program (TARP). By purchasing assets

historical data for the assets included in the high-quality liquid assets (HQLA) definition of Basel III. High quality liquid assets include cash, reserves at central banks, treasury bonds, and non-financial corporate bonds and covered bonds with the highest ratings. Additional assets like highly-rated RMBS, non-financial corporate bonds and covered bonds with [A+, BBB-] rating, and common equity shares can be included in the HQLA stock with the appropriate haircuts specified in the LCR revision of 2013 (Basel Committee on Banking Supervision (2013a)).

[9]"US banks brace for interest rate rises", Financial Times, February 24, 2011. "Excess deposits demand novel responses", Financial Times, May 30, 2012.

and equity from troubled banks from October 2008 on, the TARP led to a significant increase in the average capital ratios. For example, Treasury bought \$25 billion of preferred shares of Citigroup in October 2008 and another \$20 billion in November 2008 under the CPP.[10]

2.2.2 Expected capital shortfalls in a crisis

Acharya et al. (2012) define the systemic risk contribution of a firm i to the real economy at time t as "the real social costs of a crisis per dollar of capital shortage(t)× Probability of a crisis(t) × $SRISK_{it}$", where $SRISK_{it}$ represents the expected capital shortfall of the firm in a crisis, i.e. when the market equity index drops by 40% over the next six months. In these market conditions, $SRISK$ is based on the assumption that the book value of the (long-term) debt D_{it} of the bank will remain constant over the six-month horizon while its market capitalization MV_{it} will decrease by its six-month return in a crisis, called the long-run marginal expected shortfall ($LRMES$). The expected capital shortfall in a crisis $SRISK$ of bank i at time t is defined by

$$\begin{aligned} SRISK_{it} &= \mathrm{E}_t[k(D_{it+h} + MV_{it+h}) - MV_{it+h} | R_{mt+h} \leq -40\%] \\ &= kD_{it} - (1-k) * MV_{it} * (1 - LRMES_{it}) \end{aligned} \quad (1)$$

where R_{mt+h} is the return of the market index from period t to period $t+h$ ($h = 6$ months), k is the prudential capital ratio (8% for US financial firms), and $LRMES_{it} = -\mathrm{E}_t(R_{it+h}|R_{mt+h} \leq -40\%)$. Compared to other market-based measures of systemic risk like the CoVaR of Adrian and Brunnermeier (2010) or the Distress Insurance Premium (DIP) of Huang et al. (2012), an interesting feature of $SRISK$ is that it is a function of size and leverage which are two characteristics that the regulator finds particularly relevant when measuring solvency risk of banks. $SRISK$ can be written as a function of size, leverage and risk

$$SRISK_{it} = MV_{it} \left\{ k(Lvg_{it} - 1) - (1-k)(1 - LRMES_{it}) \right\} \quad (2)$$

where Lvg_{it} is the quasi-market leverage defined as the ratio of quasi-market assets to market capitalization ($Lvg_{it} = (MV_{it} + D_{it})/MV_{it}$). Therefore, the capital shortfall of a bank will be large if the bank is large, highly leveraged and highly sensitive to an aggregate shock as measured by $LRMES_{it}$.

These measures ($SRISK$ and $LRMES$) are available from the V-Lab website developed at NYU Stern School of Business.[11] In the global systemic risk analysis of V-Lab, $LRMES$

[10] See http://www.treasury.gov/initiatives/financial-stability/reports/Pages/TARP-Tracker.aspx.

[11] See http://vlab.stern.nyu.edu/.

is extrapolated from its short-term counterpart MES representing the daily return of the bank conditional on a 2% decline in the daily return of a global market index. The MES is derived from a time-varying beta estimated with the Dynamic Conditional Beta model of Engle (2012) that accounts for asynchronous trading around the world when measuring the comovement of bank returns with a global market index.

By definition, $SRISK$ can be negative when a bank is expected to hold a capital excess in a crisis. In Figure 4, we find two different regimes for the average $SRISK$ of banks. $SRISK$ was indeed negative for most banks before 2007. The average $SRISK$ was the lowest in the third quarter of 2006 then started to increase in 2007. $SRISK$ became positive in the fourth quarter of 2007 and reached a maximum average capital shortfall of \$16 billion in the first quarter of 2009. The average capital shortfall has remained positive since the financial crisis and bumped several times afterwards, in particular in the heat of the European sovereign debt crisis in 2011.

3 Testing the solvency-liquidity nexus of banks

As liquidity risk concerns both sides of the balance sheet, I test the interaction between solvency risk and both the short-term debt and short-term assets. Panel unit root tests indicate that the variables $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, and the solvency risk measure $SRISK_{it}/TA_{it}$ are trend stationary (see Appendix B). Therefore, the solvency-liquidity nexus is tested using a fixed-effects panel vector autoregressive (VAR) model for the $(K \times 1)$ vector of endogenous variables w_{it}

$$w_{it} = \alpha_i + \Phi w_{it-1} + \theta t + \varepsilon_{it}, \qquad t = 1, 2, ..., T_i,\ i = 1, 2, ..., N, \tag{3}$$

where α_i are bank dummies, θ is a trend parameter and Φ is a $(K \times K)$ matrix of VAR parameters.[12] Based on in-sample fit criteria, I augment the panel VAR process of eq. (3) to allow for heterogenous trend and heterogenous dynamic parameters

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \delta w_{it-1} + \varepsilon_{it}, \tag{4}$$

where ϕ_i, θ_i are $(K \times 1)$ vectors of parameters specific to bank i, δ is a $(K \times K)$ matrix of parameters with zeros on the diagonal, and $\odot$ is the Hadamard product.

[12] The parameters of eq. (3) are estimated by ordinary least squares. The bias of OLS parameter estimates is likely to be small for the considered sample since the minimum size of the time series dimension for each bank is 30 observations (i.e. $T_i \geq 30$, $\forall i$).

The estimates of the interaction parameters (δ) of equation (4) are reported in Table 1 where $w_{it} = (y_{it}, z_{it}, SRISK_{it}/TA_{it})'$. This Table reveals the empirical solvency-liquidity nexus where banks with a larger expected capital shortfall find it more difficult to raise short-term funding; the estimates suggest that a positive unit shock on the ratio of $SRISK$ to total assets produces a -1.102% shock on the short-term funding of the bank. On the other leg of the interaction, a 1% increase in the short-term debt of the bank increases its capital shortfall ratio by 0.009. Therefore, the interaction between solvency and short-term debt is asymmetric; higher solvency risk limits the access of the firm to short-term funding but a firm with more short-term debt has a higher risk of insolvency in a crisis.

This result supports the theoretical literature explaining bank runs based on the strength of the banks fundamentals (Allen and Gale (1998); Diamond and Rajan (2005), etc.), and describing the interaction between liquidity and solvency problems of banks (Diamond and Rajan (2005); Morris and Shin (2008); Rochet and Vives (2004)). The results also give empirical support to the recent speeches by Carney (2013) and Tarullo (2013) explaining that the repair of banks' balance sheet (i.e. higher capital levels) gives the confidence to investors and creditors to continue to provide funding to banks.

From Table 1, we also note that short-term assets do not relate to the other variables in the vector w_{it}, suggesting that banks are not able to adjust their stock of short-term assets to solvency risk or short-term funding conditions in a timely fashion. It also reflects a liquidity hoarding tendency of banks where banks prefer to sell long-term assets to repay short-term creditors. Banks prefer to hold the short-term assets for precautionary reasons or for investing in fire sale assets of other financial institutions that are expected to generate high future returns (Acharya et al. (2009)).

In the rest of this section, I test alternative solvency risk measures to predict the short-term balance sheet of banks in Section 3.1, for the interaction between profitability and solvency risk in predicting the short-term balance sheet (Section 3.2), and for the robustness of the solvency-liquidity nexus in Section 3.3.

3.1 Testing alternative solvency risk measures

I report the tests of alternative measures of solvency risk to predict the short-term balance sheet (y_{it} and z_{it}) in Table 2, controlling for the market-to-book ratio as the regression includes both accounting and market variables. The columns (1) to (6) show the individual impact of each measure. From this Table, the regulatory capital ratios ($T1CR$ and $T1LVGR$) do not appear to be related to either side of the short-term balance sheet. Market measures of risk like the realized quarterly volatility is significant (at 5%) to predict short-term assets but this result does not hold in the regression including all solvency risk factors (column (7)). Then, the sensitivity of the bank's return to market shocks measured by the the Dynamic Conditional Beta (DCB) of Engle (2012), and the contribution of the bank to systemic risk measured by the Delta CoVaR of Adrian and Brunnermeier (2010) are not significant drivers of the short-term balance sheet either. When all solvency risk factors are included in the regression (column (7)), only $SRISK$ per unit of asset and the market-to-book ratio are significant at the 1% level to predict the short-term debt level of banks.

The results of Table 2 suggest that not all solvency risk factors can predict the shocks in the short-term balance sheet of banks. A bank with higher solvency risk in isolation does not necessarily get restricted access to short-term funding. However, banks lose short-term funding when they are expected to be insolvent in a systemic crisis. An explanation for this observation is based on the liquidation costs of a firm's illiquid assets in a crisis. Shleifer and Vishny (1992) show that when a firm is individually in distress, its liquidation costs are not as high because the firm can find buyers in the same industry who value its illiquid assets at a price close to their value in best use. In a crisis, however, the potential buyers in the industry will likely also meet difficulties to find funding and will not be able to buy those assets. The firm will then have to sell its illiquid assets to less specialized buyers outside the industry at a higher liquidation cost.

A bank that is expected to be insolvent in a crisis will be facing high liquidation costs and will consequently not be able to raise cash. Creditors who anticipate this based on publicly available data (as those used to derive $SRISK$) will run from the bank as they expect the bank will not be able to repay them. The liquidation costs during the 2008 financial crisis were exacerbated by the huge gap between short-term assets and short-term debt observed in Section 2. As a result, banks had no choice but to sell illiquid assets to repay creditors when losing access to short-term funding.

In-sample fit criteria show the superiority of $SRISK$ in Table 3 (first column) to predict short-term funding; the adjusted R^2 is 15.7% compared to an adjusted R^2 around 11% for the regressions with the alternative solvency risk measures of Table 2.[13] In order to identify what works so well in $SRISK$ for predicting the short-term funding of banks, Table 3 also reports the estimates of the different components of $SRISK$ highlighted in eq. (2). The Table shows that the improvement in in-sample fit rather comes from the ratio of market

[13]Note that all reported R^2 are on the first differences ($w_{it} - w_{it-1}$). The R^2 of levels (w_{it}) are very high (around 90%) given the bank specific constant, trend and autoregressive parameters.

capitalization to total assets (MV/TA) than from the long-run marginal expected shortfall ($LRMES$) or the quasi-market leverage (Lvg). The main difference between Lvg and the MV/TA ratio is a different combination of book and market values; the ratio MV/TA is the product of the book leverage ratio ($T1LVGR_{it}$) and the market-to-book ratio (MV_{it}/BV_{it})

$$\frac{MV_{it}}{TA_{it}} = \frac{BV_{it} * \left(\frac{MV_{it}}{BV_{it}}\right)}{TA_{it}} \simeq T1LVGR_{it} * \left(\frac{MV_{it}}{BV_{it}}\right),$$

whereas $Lvg_{it} = 1 + \frac{D_{it}}{MV_{it}}$ is not a function of the book leverage ratio. A potential argument against using market values to test for the solvency-liquidity nexus is that market values also incorporate information about liquidity risk. The results of Table 3 however suggest that both the book solvency ratio — informing about pure solvency shocks — and the market-to-book ratio — informing about how faster the market values fall compared to book values — are important for predicting the short-term debt of banks. The ratio MV/TA is highly correlated to the book leverage ratio (0.91) and less correlated to the market-to-book ratio (0.44); solvency risk amplified by market shocks explain banks' access to short-term funding and neither the market-to-book or the leverage ratio taken separately, nor their linear combination predict short-term funding.

The modest improvement in fit due to the downside risk of the bank $LRMES$ (0.66% increase of adjusted R^2 from column 4 to column 5, Table 3) is consistent with the sample period that contains several episodes of market stress. In a crisis, all is already function of the aggregate shock. However, measuring the downside risk is important preemptively; I find increasing out-of-sample forecasting errors when MV/TA is employed in the panel VAR instead of $SRISK/TA$ for predicting the short-term balance sheet of banks during the European sovereign debt crisis (especially with the dynamic forecasting exercise of Section 4).

3.2 Interaction between solvency and profitability

In Perotti and Suarez (2011), both liquidity risk and profitability are increasing functions of the short-term debt level of the bank. A bank will indeed demand more short-term funding when it finds profitable investment opportunities. Its liquidity risk will also increase as its short-term debt will be invested in long-term profitable assets. The impact of the profitability of the bank measured by its net income divided by total assets is found to be positive on short-term debt and negative on short-term assets in Table 4 (Panel A), but these parameters are not significant at the 5% level.

The parameters of eq. (4) are however expected to vary with the state of the bank and/or the aggregate liquidity conditions. In good times, short-term funding and short-term assets are the result of management decisions and are driven by demand factors. As mentioned, banks with profitable opportunities will demand more short-term funding. In bad times, supply factors determine how much short-term debt a bank can raise and the short-term assets adjust accordingly. One way to disentangle supply and demand effects on the bank characteristics is to augment equation (4) with a state variable

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \delta w_{it-1} + \gamma w_{it-1} * s_{t-1} + \omega s_{t-1} + \varepsilon_{it} \tag{5}$$

where ω is a $(K \times 1)$ vector of parameters, γ is a $(K \times K)$ matrix of parameters with zeros on the diagonal, and the state variable s_t could be a bank characteristic or a common factor. For example, Cornett et al. (2011) use the TED spread (the difference between 3-month LIBOR rate and T-bill rate) to reflect the change in the management of liquidity risk exposures of banks during the financial crisis.[14] In Table 4 (Panel B), I show that a good candidate for the state variable is simply a dummy variable equal to one when $SRISK$ is positive ($s_{it} = 1_{\{SRISK_{it}>0\}}$), i.e. when the bank is expected to have a capital shortfall in a crisis.

This distinction between states where $SRISK$ is positive or negative appears to be important when measuring the effect of the profitability of the bank on its short-term balance sheet. Indeed, a bank with a higher net income has a larger access to short-term funding while it does not hold as much liquid assets. In Table 4, this beneficial effect of the bank's profitability on its short-term balance sheet appears to be true only when the bank' $SRISK$ is negative, i.e. when the bank is adequately capitalized to survive a crisis ($s_{it} = 0$). When the bank is expected to be capital-constrained in a crisis ($s_{it} = 1$), the effect of profitability on its balance sheet disappears ($\delta + \gamma \simeq 0$), and only supply factors predict the short-term debt of the bank.

An interesting observation is that the contrasting impact of profitability on the short-term balance sheet can be reproduced when I allow for parameter breaks over time

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \delta w_{it-1} + \delta_c w_{it-1} * c_t + \delta_{pc} w_{it-1} * pc_t + \omega_c c_t + \omega_{pc} pc_t + \varepsilon_{it} \tag{6}$$

where c_t and pc_t are dummy variables indicating whether the quarter t belongs to the financial crisis period (2007Q1-2009Q4) or the post crisis period (2010Q1-2013Q1) respectively. In Table 11 (Appendix C), we observe that the impact of the net income on the short-term

[14] The TED spread is however not significant to predict the short-term balance sheet for the sample considered in this paper (cf.. Section 3.3.2).

balance sheet also disappeared during the financial crisis ($\delta + \delta_c \simeq 0$). This Table further shows that $SRISK$ was significant only during the financial crisis (when there was actual liquidity stress). The results tend to confirm the interpretation of $SRISK$ as a supply factor for short-term funding, and of the net income as a demand factor when the firm is adequately capitalized.

Based on the estimates of the panel VAR, I can derive the impulse response functions (IRF) of w_{it} where $w_{it} = (y_{it}, z_{it}, NetIncome_{it}/TA_{it}, SRISK_{it}/TA_{it})'$. I collect the orthogonalized shocks of the VAR from a Cholesky decomposition of the covariance matrix of ε_{it} of eq. (4), with the ordering given by $[NetIncome_{it}/TA_{it} \rightarrow SRISK_{it}/TA_{it} \rightarrow y_{it} \rightarrow z_{it}]$. This ordering is motivated by the observation that exogenous shocks first impact a firm via its activities and is translated into the net income, markets react by adjusting their assessment of the capital shortfall $SRISK$, this in turn affects how much funding the bank can access and the short-term assets adjust in consequence.

Due to the heterogenous autoregressive parameters of eq. (4), firms will have heterogeneous responses to sigma shocks. In Figure 5, I show the median impulse response function to orthogonalized sigma shocks between the 25% and the 75% IRF quantiles to assess the heterogeneity in impulse responses across firms. In general, the IRF that concerns short-term funding are more heterogenous (impact of other variables shocks on short-term debt and impact of short-term debt shocks on other variables). The range between impulse responses quantiles is also wider for the interaction between $SRISK$ and the short-term balance sheet. For some banks, it takes three years for the impact of $SRISK$ shocks on short-term funding to vanish whereas the solvency shocks of other banks have a more definitive impact on their short-term funding. Then, the impulse response functions well illustrate previous findings on the asymmetric impact of shocks between $SRISK$ and the short-term balance sheet, and between the net income and the short-term debt.

The impact of orthogonalized sigma shocks will be different when I differentiate between capital-constrained vs. adequately capitalized banks based on the parameters of eq. (5). Figure 6 shows the gap in median impulse response functions between adequately capitalized versus capital-constrained firms. The solvency-liquidity nexus appears to be exacerbated for capital-constrained banks; the impact of solvency shocks on short-term funding doubles compared to adequately capitalized banks, while the response of short-term debt to shocks in other bank characteristics (net income and short-term assets) is less important and vanishes more rapidly. For capital-constrained banks, only the solvency-liquidity nexus appears to explain the short-term balance sheet.

3.3 Robustness of the solvency-liquidity nexus

3.3.1 Robustness to TARP

On October 14, 2008, the U.S. government announced a series of measures — the Troubled Asset Relief Program (TARP) — to restore financial stability. Under the TARP, the Treasury Department launched the Capital Purchase Program (CPP) and the Federal Deposit Insurance Corporation launched the Temporary Liquidity Guarantee Program (TLGP). Under the CPP, Treasury injected $205 billion capital into banks by buying warrants, common shares, and preferred shares.[15] Under the TLGP, the FDIC allowed financial institutions to retain and raise funding by giving a guarantee on existing noninterest-bearing transaction accounts and certain newly issued senior unsecured debt. Data on the amount and maturity of total unsecured debt issued by banks and guaranteed by the FDIC are publicly available.[16] It is possible to derive the amount of short-term debt a bank would have had if it did not have access to TLGP funding. The solvency-liquidity nexus estimates hardly change when TLGP funding is not taken into account. It is however impossible to project this scenario on the other variables of the panel VAR as it requires to know where TLGP funding was invested and how markets would have reacted in this scenario.

If we assume that banks received help from the TARP when they actually needed it, the amount of CCP capital injected and the amount of TLGP funding received are realized measures of the bank's capital shortfall and liquidity shortfall, respectively. The largest banks received the largest injections of capital and liquidity. Looking at data from the second quarter of 2008, I test different bank characteristics and risk measures to explain their capital and liquidity shortfalls divided by their total assets. In Table 5, I report the estimates of cross-sectional regressions for a sample of 17 banks that received both capital and liquidity interventions. It appears that the regulatory capital ratios are the most important factors explaining government interventions. After controlling for the size, we observe that banks that received help from the CPP and banks that received help from the TLGP have different profiles. Banks that received government secured debt had low Tier 1 leverage ratios (ratio of Tier 1 capital to total assets), whereas banks that received capital injections had low Tier 1 Common capital ratios (ratio of Tier 1 Common capital to risk-weighted assets). Banks with high liquidity shortfalls in 2008Q4 had a large short-term balance sheet, high cost of funding, and high market beta (or $LRMES$) in 2008Q2. Conversely, banks with high capital

[15] http://www.treasury.gov/initiatives/financial-stability/TARP-Programs/bank-investment-programs/cap/Pages/overview.aspx

[16] See http://www.fdic.gov/regulations/resources/TLGP/index.html

shortfalls were more traditional banks with a large long-term balance sheet (deposits and loans), high yields on earning assets, and low market beta (among the banks that received government interventions).

3.3.2 Common factors

The short-term balance sheets of firms are expected to co-move according to the aggregate liquidity conditions. To capture these common effects, I consider the macroeconomic and financial factors that are used in Fontaine and Garcia (2012) to relate to their factor measuring the value of funding liquidity, and will test the robustness of the solvency-liquidity nexus to these factors in the next section. The sensitivity of the short-term balance sheet (and its covariates) to the common factors is tested in

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \beta' f_{t-1} + \varepsilon_{it} \tag{7}$$

where $w_{it} = (y_{it}, z_{it}, NetIncome_{it}/TA_{it}, SRISK_{it}/TA_{it})'$, and f_t is a vector of common factors. Note that common factors do not necessarily need to be lagged but this allows for the derivation of one-step ahead forecasts for w_{it} without specifying a model for the common factors. The estimated parameters of common factors of eq. (7) are reported in Table 6.[17]

Interest rates are expected to play an important role on the short-term balance sheet. Three factors related to interest rates are considered; the level of interest rates is captured by the Fed funds rate, the difference between long-term and short-term rates is measured by the slope factor of the Treasury yield curve, and the TED spread reflects the perceived counterparty risk of interbank loans compared to Treasury loans. The TED spread is usually referred as an aggregate funding liquidity risk factor (Cornett et al. (2011); Fontaine and Garcia (2012)). In the sample considered, the TED spread is not significant to explain the short-term balance sheet directly but has a negative impact on the profitability of banks and a positive impact on their solvency risk (measured by $SRISK$).

The Treasury slope factor measures the difference between long-term and short-term interest rates. A steeper term structure indicates higher profitability of investing short-term funding in long-term assets (Fontaine and Garcia (2012)). This factor also reflects business cycles and could be interpreted as a demand factor for liquidity. It is therefore not surprising that short-term debt increases with a steeper slope of the Treasury yield curve.

[17]Data sources of common factors: Federal Reserve Board Selected Interest Rates - H.15 (Fed fund rate); FRB Money Stock Measures - H.6 (M2 money supply growth); FRB Financial Accounts of the United States - Z.1 (MMMF flows, mortgage growth); Department of the Treasury (Treasury yield curves); Bloomberg (VIX).

The positive and significant coefficient of the Fed funds rate on short-term debt is more surprising and possibly reflects an endogenous response of the Federal Reserve to funding conditions during the financial crisis. The impact of interest rates on bank's funding may however be subtler. Diamond and Rajan (2005) explain that higher interest rates do not always lead to lower excess demand for liquidity because of the effect of bank failures. Higher interest rates cause more banks to become insolvent and run (because of decreasing assets value). The excess demand will increase with interest rates if by failing, banks absorb more liquidity than when solvent. Through these two channels (Fed interventions and firms failures), solvency risk has an aggregate endogenous feedback on the level of interest rates.

Mortgage growth (MTG) increases the demand for short-term debt. MTG is referred in Fontaine and Garcia (2012) as a factor exclusively affecting the demand for liquidity by increasing the pool of illiquid assets in the economy. Other considered factors include flight-to-quality variables related to Money Market Mutual Funds (MMMF). The growth in MMMF assets (MMG) increases the supply of funding to banks via the shadow banking sector (Adrian and Shin (2009); Fontaine and Garcia (2012)), but short-term funding supply decreases when MMMF assets are allocated to safer assets like time deposits (MMA1) or government-sponsored securities (MMA2).

The coefficient associated with MMA1 is negative and significant at the 1%. This result could, however, simply reflect the increase of the deposit insurance limit of the Federal Deposit Insurance Corporation (FDIC) in 2008Q4. Acharya and Mora (2013) document the shift from time deposits and debt issued by banks (and MMA1) to government-sponsored securities (and MMA2), and the "liquidity reversal" in 2008Q4 where MMA1 started to increase again. When the FDIC deposit insurance limit increased from 100K to 250K in the fourth quarter of 2008, uninsured deposits included in short-term debt shifted to the long-term part of the balance sheet. Therefore, the negative impact of MMA1 on banks' short-term debt partly corresponds to the reallocation in 2008Q4 of some previously uninsured time deposits to the long-term debt within banks' balance sheets.

We also note the positive coefficient of the VIX as banks' exposure to short-term debt was the highest when the VIX peaked during the financial crisis. Finally, short-term assets are not sensitive to any of the considered factors. While the level of short-term assets adjusts to shocks in other parts of the balance sheet, it is not directly affected by financial and macroeconomic conditions.

3.3.3 Robustness of the solvency-liquidity nexus to common factors

I test the robustness of the solvency-liquidity nexus to the presence of common factors in

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \lambda' g_{it-1} + \beta' f_{t-1} + \varepsilon_{it} \tag{8}$$

where $w_{it} = (y_{it}, z_{it}, NetIncome_{it}/TA_{it}, SRISK_{it}/TA_{it})'$, g_{it} is a $((2 * K + 1) \times 1)$ vector stacking w_{it}, $w_{it} * s_{it}$ and s_{it} in a single column, λ is a $((2 * K + 1) \times 1)$ vector containing the δ, γ and ω parameters, and f_t is the vector of macroeconomic and financial factors identified in Section 3.3.2.

Chudik and Pesaran (2013) propose an alternative modeling strategy based on the Common Correlated Effects (CCE) of Pesaran (2006) where the unobserved common factors are proxied by the cross-sectional averages of the dependent variable and the regressors

$$w_{it} = \alpha_i + \phi_i \odot w_{it-1} + \theta_i t + \lambda' g_{it-1} + \sum_{l=0}^{1} \varphi_l' \bar{w}_{t-l} + \kappa' \bar{g}_{t-1} + \varepsilon_{it} \tag{9}$$

where $\bar{w}_{t-l} = N^{-1} \sum_{i=1}^{N} w_{it-l}$ and $\bar{g}_t = N^{-1} \sum_{i=1}^{N} g_{it}$.

The estimation results of eq. (8) and eq. (9) are reported in Table 7. The fit improves considerably when common factors are included. The best in-sample performance is found with the CCE model for all elements of w_{it}. However, the CCE model counts a contemporaneous factor (average of the dependent variable) while the model with macro and financial factors only includes lagged factors. The macro-financial model is therefore more convenient for forecasting and the loss of in-sample fit is relatively small compared to the CCE model.

The solvency-liquidity nexus holds when I control for cross-sectional dependence. The interaction term between the profitability and $SRISK$ is however not as important (not significant at the 5%). The impulse response functions do not qualitatively change either when macroeconomic and financial factors are considered.

3.3.4 Short-term debt components and long-term leverage

The different components of short-term debt (repos, uninsured deposits, commercial papers, etc.) have very different characteristics and may not react to solvency risk with the same magnitude. Table 12 (Appendix C) reports the parameter estimates of eq. (4) where the dependent variable in each column is a different component (in logarithm) of the short-term debt available from FR 9-YC reports. $SRISK$ predicts most of the components of the short-term debt; it is significant at the 1% level for wholesale funding (Fed funds, repos, and commercial papers), and at the 5% level for retail funding (uninsured time deposits and foreign office deposits).

The expected capital shortfall $SRISK$ is only related to the short-term part of the balance sheet and does not predict long-term leverage. Table 8 shows that the long-term balance sheet is not related to $SRISK$. The long-term debt only reacts to short-term assets and the change in long-term assets.

Other robustness checks (not reported in this paper) show that the interaction between solvency and liquidity remains with homogenous dynamic parameters ($\phi_i = \phi$, $\forall i$), homogenous trend parameters ($\theta_i = \theta$, $\forall i$), without trend ($\theta_i = 0$, $\forall i$), and when a break in 2008Q4 is included in the trend. These results tend to confirm the robustness of the solvency-liquidity nexus. In the next section, I test for the out-of-sample forecasting performance of the solvency-liquidity nexus in predicting the short-term balance sheet of banks.

4 Forecasting the short-term balance sheet

To test for the out-of-sample predictive performance of the solvency-liquidity nexus, I conduct two forecasting exercises. Both exercises are based on a fixed estimation period from 2000Q1 to 2010Q4 to forecast the balance sheet of banks over the four quarters of 2011. The information is updated each quarter in the one-step ahead forecasts ($\hat{w}_{it+1|t}$), while there is no information update in the dynamic forecasts ($\hat{w}_{it+h|t}$). The out-of-sample period corresponds to the European sovereign debt crisis, funding conditions were not as tight as during the financial crisis in the US but there is a total decline of $161 billion in short-term funding of US banks during this period.

The root-mean square forecasting error (RMSFE) of the one-step ahead forecasting exercise are reported in Table 9. In this Table, I report the RMSFE of the short-term debt and short-term assets individually (Panel A and B), as well as the RMSFE of their difference (Panel C). As already mentioned, the liquid asset shortfall is a measure of the exposure of banks to funding liquidity risk; the wider the gap in the short-term balance sheet, the more vulnerable the bank to runs. As this paper studies the liquidity-solvency nexus of banks, I also report the RMSFE of this liquid asset shortfall for capital-constrained (Panel D) vs. adequately capitalized banks (Panel E).

Four models are considered: a univariate autoregressive model (AR), the panel VAR model of eq. (4) (VAR), the panel VAR model of eq. (5) that allows for the interaction of bank characteristics with the state variable $s_{it} = 1_{\{SRISK_{it}>0\}}$ (INT), and the model including all these features together with the macroeconomic and financial factors (eq. (8)) (CF).

The assumption on the trend appears to be the most important model characteristic to impact forecasting errors. To check for the robustness of the forecasting results, I report the RMSFE of these models for different trend assumptions (heterogeneous trends, homogenous trend, no trend, and a break in the homogenous trend in 2008Q4).

For the one-step ahead forecasts, the best model is the panel VAR model that accounts for the interaction of bank characteristics with $SRISK$ (INT), and that assumes a break in the trend in the fourth quarter of 2008. When the trend parameters are constant over time, the model with common factors (CF) performs the best for the liquid asset shortfall as common factors reflect the changing aggregate funding conditions after the financial crisis. In the last three columns of Table 7, I report the increase in RMSFE when a particular bank variable is not included in the panel VAR model.This Table shows that omitting $SRISK$ increases the forecasting errors of the liquid asset shortfall considerably, and particularly for capital constrained banks during 2011. However, the panel VAR model or the interaction with solvency risk (INT) does not improve the forecasts of adequately capitalized banks.

I obtain very similar results for the dynamic forecasts and therefore do not report their RMSFE. Note that the RMSFE of dynamic forecasts are larger compared to the errors of one-step ahead forecasts due to the absence of information updates over the forecasting horizon. The model with interaction with $SRISK$ (INT) and a break in the trend after the financial crisis is also the preferred model according the RMSFE of dynamic forecasts. The cross-sectional average dynamic forecasts obtained with this model for the short-term balance sheet levels and flows over 2011Q1-2013Q1 are illustrated in Figure 7. It turns out that the model is outstanding at forecasting short-term financing flows but does a less good job at forecasting short-term asset flows, which are not sensitive to the factors considered in the model.

In Figure 8, I show the average dynamic forecasts of the liquid asset shortfall across all banks, as well as for the subsamples of capital-constrained vs. adequately capitalized banks. As mentioned in the introduction, the liquid asset shortfall of capital-constrained banks spiked in the first quarters of 2007 and suddenly dropped afterwards due to the sudden freeze of short-term funding markets. In the first quarter of 2011, the average liquid asset shortfall of capital-constrained banks became negative; capital-constrained firms had less exposure to funding liquidity risk than adequately capitalized banks for the first time over the sample period. The model predicts this reversal in the solvency-liquidity nexus and predicts well the average excess of liquidity of capital-constrained banks during this period.

5 Conclusion

This paper reveals the empirical solvency-liquidity nexus of banks. While the interaction between solvency and liquidity has been well studied in the theoretical economic literature, this relationship tends to be omitted in the new capital and liquidity regulatory standards introduced under Basel III. In this paper, I test the solvency-liquidity nexus by examining the short-term balance sheet and the solvency risk measures of a sample of US bank holding companies over 2000-2013.

I find that the expected capital shortfall of a bank in a crisis ($SRISK$) predicts how much short-term funding the bank has access to. Conversely, when the bank holds more short-term debt, its risk of insolvency in a crisis increases. This result appears to be strong under many robustness checks and supports the theoretical models of the interaction between solvency and liquidity risks and its amplification (aggregate) effects leading to systemic risk.

Importantly, not all solvency risk measures predict the bank's access to short-term debt. The expected capital shortfall $SRISK$ interacts well with the level of short-term funding of the bank compared to other solvency risk measures because (i) it is a measure of the bank's exposure to aggregate risk, and (ii) it combines both book and market values. Suppliers of liquidity are mostly concerned with the vulnerability of the bank to an aggregate crisis due to the high liquidation costs the distressed bank will face in the presence of fire sales. When the crisis happens, 'pure' solvency risk (measured by the Tier 1 leverage ratio) amplified by market shocks explains the bank access to short-term funding.

The expected capital shortfall of the bank under stress also interacts with its profitability in determining its short-term balance sheet. While a profitable bank gets a larger access to short-term funding and does not hold as much liquid assets, the impact of the bank's profitability on its liquidity profile tends to disappear when the bank is expected to be capital-constrained in a crisis.

The solvency-liquidity nexus provides useful information for forecasting the short-term financing flows during 2011 (European sovereign debt crisis). I show that the forecasting errors of the liquid asset shortfall of banks increase considerably when the stressed solvency risk measure is not included in the regression.

Overall, the results of this paper suggest that the solvency-liquidity nexus should be accounted for when designing liquidity monitoring tools and prudential requirements. This finding contrasts with Basel regulation where solvency and liquidity risks are treated separately and gives empirical support for an additional capital requirement for banks with large exposure to short-term funding.

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Dep. variable:	y_{it}	z_{it}	$(\text{SRISK/TA})_{it}$
$(\text{SRISK/TA})_{it-1}$	-1.120**	0.074	
	(0.244)	(0.114)	
z_{it-1}	-0.040		-0.001
	(0.023)		(0.002)
y_{it-1}		-0.003	0.009**
		(0.022)	(0.002)
R^2 (%)	20.811	22.157	15.151
Adj. R^2 (%)	15.430	16.868	9.429

Table 1: **Testing the solvency-liquidity nexus.** Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks. SRISK is the expected capital shortfall of the bank in a crisis.

	(1)		(2)		(3)		(4)		(5)		(6)		(7)	
Dep. variable:	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}
T1CR_{it-1}	0.301	-0.070											0.041	-0.089
	(0.337)	(0.134)											(0.552)	(0.360)
T1LVGR_{it-1}			0.508	-0.074									-1.148	-0.142
			(0.491)	(0.305)									(0.875)	(0.832)
Real Vol_{it-1}					-0.438	0.919*							2.286*	0.151
					(0.412)	(0.450)							(1.119)	(1.491)
ES_{it-1}							-0.250	0.412					-0.697*	0.364
							(0.159)	(0.203)					(0.397)	(0.644)
DCB_{it-1}									-0.046	0.030			-0.021	0.002
									(0.027)	(0.034)			(0.028)	(0.040)
$\triangle\text{CoVaR}_{it-1}$											-0.402	0.188	0.094	0.102
											(0.761)	(0.784)	(0.750)	(0.801)
$(\text{SRISK/TA})_{it-1}$													-1.579**	-0.078
													(0.072)	(0.141)
MB_{it-1}	0.042	-0.014	0.042	-0.014	0.035	-0.001	0.033	0.000	0.036	-0.011	0.041	-0.015	-0.053**	-0.005
	(0.026)	(0.017)	(0.025)	(0.017)	(0.027)	(0.017)	(0.026)	(0.017)	(0.025)	(0.019)	(0.024)	(0.017)	(0.017)	(0.022)
R^2 (%)	16.621	22.196	16.604	22.192	16.581	22.393	16.623	22.424	16.645	22.235	16.542	22.194	21.461	22.428
Adj. R^2 (%)	10.955	16.909	10.937	16.905	10.913	17.119	10.957	17.153	10.980	16.951	10.871	16.907	15.868	16.904

Table 2: **Testing alternative solvency risk measures**. Estimates from pooled OLS regression with bank dummies, time trends and heterogeneous AR parameters. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$. T1CR: Tier 1 Common Capital Ratio, T1LVGR: Tier 1 Leverage Ratio, RealVol: Realized volatility, DCB: Dynamic Conditional Beta (Engle (2012)), $SRISK/TA$ = SRISK/Total Assets, MB: market to book equity ratio. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks.

	(1)		(2)		(3)		(4)		(5)		(6)	
Dep. variable:	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}	y_{it}	z_{it}
$(\text{SRISK/TA})_{it-1}$	-1.439**	0.010										
	(0.105)	(0.110)										
LRMES_{it-1}			-0.162	0.205							-0.080	0.195
			(0.096)	(0.111)							(0.110)	(0.117)
Lvg_{it-1}					-0.002	0.001					-0.002	0.000
					(0.001)	(0.001)					(0.001)	(0.001)
$(\text{MV/TA})_{it-1}$							0.930**	-0.002			0.925**	0.002
							(0.051)	(0.049)			(0.052)	(0.046)
$(\text{SMV/TA})_{it-1}$									1.369**	-0.021		
									(0.080)	(0.116)		
MB_{it-1}	-0.048**	-0.014	0.032	-0.002	0.032	-0.007	-0.050**	-0.014	-0.051**	-0.013	-0.060	-0.001
	(0.016)	(0.022)	(0.025)	(0.019)	(0.027)	(0.019)	(0.019)	(0.021)	(0.016)	(0.022)	(0.020)	(0.024)
R^2 (%)	21.110	22.191	16.714	22.443	16.701	22.254	20.725	22.191	21.338	22.192	20.931	22.446
Adj. R^2 (%)	15.749	16.904	11.055	17.173	11.041	16.971	15.338	16.903	15.993	16.905	15.473	17.092

Table 3: **Testing SRISK components**. Estimates from pooled OLS regression with bank dummies, time trends and heterogenous AR parameters. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$. MV: market capitalization, TA: total assets, RealVol: Realized volatility, $SRISK/TA$ = SRISK/Total Assets, LRMES: Long-Run Marginal Expected Shortfall, Lvg: quasi-market leverage, MB: market to book equity ratio, SMV/TA = MV*(1-LRMES)/TA. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks.

	Panel A: No interaction with $s_{it} = 1_{\{SRISK_{it}>0\}}$				Panel B: Interaction with $s_{it} = 1_{\{SRISK_{it}>0\}}$			
Dep. variable:	y_{it}	z_{it}	$(\mathrm{NI/TA})_{it}$	$(\mathrm{SRISK/TA})_{it}$	y_{it}	z_{it}	$(\mathrm{NI/TA})_{it}$	$(\mathrm{SRISK/TA})_{it}$
$(\mathrm{SRISK/TA})_{it-1}$	-1.063**	-0.028	-2.225**		-0.935**	-0.120	-1.681**	
	(0.245)	(0.118)	(0.301)		(0.261)	(0.101)	(0.080)	
$(\mathrm{SRISK/TA})_{it-1} * s_{it-1}$					-0.408	1.757*	-5.871**	
					(0.751)	(0.767)	(1.767)	
$(\mathrm{NI/TA})_{it-1}$	2.354	-4.228		-1.217**	9.704**	-7.944*		-2.809**
	(2.278)	(2.331)		(0.389)	(3.290)	(3.716)		(0.935)
$(\mathrm{NI/TA})_{it-1} * s_{it-1}$					-9.902*	6.315		2.134*
					(4.396)	(5.183)		(0.937)
z_{it-1}	-0.038		-0.015	-0.002	-0.033		-0.035	-0.001
	(0.023)		(0.020)	(0.002)	(0.022)		(0.022)	(0.003)
$z_{it-1} * s_{it-1}$					-0.021*		0.078*	-0.0008
					(0.008)		(0.032)	(0.002)
y_{it-1}		-0.004	-0.067**	0.008**		-0.002	-0.031	0.008**
		(0.021)	(0.026)	(0.002)		(0.022)	(0.021)	(0.002)
$y_{it-1} * s_{it-1}$						-0.007*	-0.080*	0.002
						(0.010)	(0.032)	(0.002)
s_{it-1}					0.347*	0.066	0.094	-0.018
					(0.144)	(0.159)	(0.187)	(0.018)
R^2 (%)	20.870	22.318	41.925	15.787	21.278	22.562	44.474	16.184
Adj. R^2 (%)	15.450	16.997	37.977	10.062	15.715	17.089	40.579	10.304

Table 4: **Testing the interaction between solvency and profitability.** Estimates from pooled OLS regression with bank dummies, time trends, and heterogeneous AR parameters. Panel A: model of eq. (5) without state variable. Panel B: model of eq. (5) with state variable $s_{it} = 1_{\{SRISK_{it}>0\}}$. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, $(NI/TA)_{it} = NetIncome_{it}/TotalAssets_{it}$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks. SRISK is the expected capital shortfall of the bank in a crisis.

	CPP/TA	TLGP/TA
Cst	4.280	-7.478
	(6.088)	(8.948)
T1LVGR	0.222	-0.941*
	(0.269)	(0.395)
T1CR	-0.285*	0.181
	(0.106)	(0.155)
log(TA)	-0.042	0.806*
	(0.240)	(0.352)
R^2 (%)	37.701	72.217
Adj. R^2 (%)	23.325	65.805

Table 5: **Testing factors explaining capital and liquidity injections under the TARP.** Estimates from cross-sectional OLS regression. Dependent variables: the amount of capital received under the CPP divided by total assets (CPP/TA), the amount of total unsecured debt guaranteed by the FDIC divided by total assets (TLGP/TA). T1LVGR: Tier 1 Leverage ratio, T1CR: Tier 1 Common Capital Ratio, log(TA): logarithm of total assets, as of 2008Q2. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 17 banks.

Dep. variable:	y_{it}	z_{it}	$(NI/TA)_{it}$	$(SRISK/TA)_{it}$
Fedfund rate$_{t-1}$	0.045**	0.001	-0.031	-0.005
	(0.011)	(0.014)	(0.019)	(0.003)
Treasury slope$_{t-1}$	0.077**	0.013	-0.055	0.006**
	(0.023)	(0.026)	(0.029)	(0.001)
TED$_{t-1}$	0.003	0.043	-0.172**	0.009*
	(0.015)	(0.024)	(0.048)	(0.004)
VIX$_{t-1}$	0.003**	0.0004	-0.002	-0.00005
	(0.001)	(0.001)	(0.001)	(0.0002)
M2G$_{t-1}$	-4.308**	-0.366	0.255	0.154
	(1.351)	(1.035)	(1.078)	(0.171)
MTG$_{t-1}$	3.760**	-1.281	0.946	-0.748*
	(1.120)	(1.455)	(1.236)	(0.368)
MMG$_{t-1}$	0.463**	-0.308	-0.197	0.008
	(0.172)	(0.223)	(0.336)	(0.034)
MMA1$_{t-1}$	-1.994**	1.058	-0.592	-0.300**
	(0.455)	(0.601)	(0.628)	(0.073)
MMA2$_{t-1}$	0.265	-0.291	-1.510**	-0.181*
	(0.222)	(0.383)	(0.509)	(0.086)
R^2 (%)	21.996	23.816	44.559	19.217
Adj. R^2 (%)	16.399	18.350	40.609	13.461

Table 6: **Testing common factors.** Estimates from pooled OLS regression with bank dummies, time trends, heterogeneous AR parameters and common factors. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks. Treasury slope is the slope factor of the Treasury yield curve. M2G: money supply growth (M2). MTG: mortgage assets growth. MMG: MMMF assets growth. MMA1: proportion of MMMF assets allocated to time deposits. MMA2: proportion of MMMF assets allocated to Treasury, agency, or municipal bonds.

	No Common Factor				Common Factors				Common Correlated Effects			
Dep. variable:	y_{it}	z_{it}	NI/TA	SRISK/TA	y_{it}	z_{it}	NI/TA	SRISK/TA	y_{it}	z_{it}	NI/TA	SRISK/TA
$(\text{SRISK/TA})_{it-1}$	-0.935**	-0.120	-1.681**		-0.847**	-0.178	-1.417**		-0.900**	-0.137	-1.649**	
	(0.261)	(0.101)	(0.080)		(0.318)	(0.096)	(0.117)		(0.280)	(0.106)	(0.093)	
$(\text{SRISK/TA})_{it-1} * s_{it-1}$	-0.408	1.757*	-5.871**		-0.687	1.291	-5.108**		-1.413	2.384*	-5.250**	
	(0.751)	(0.767)	(1.767)		(0.853)	(0.861)	(1.736)		(0.974)	(1.009)	(1.976)	
$(\text{NI/TA})_{it-1}$	9.704**	-7.944*		-2.809**	8.111*	-7.564*		-2.639*	8.512*	-7.964*		-2.205**
	(3.290)	(3.716)		(0.935)	(3.677)	(3.575)		(1.026)	(3.542)	(3.905)		(0.771)
$(\text{NI/TA})_{it-1} * s_{it-1}$	-9.902*	6.315		2.134*	-8.087	4.817		2.034*	-7.181	7.926		2.105*
	(4.396)	(5.183)		(0.937)	(4.788)	(4.920)		(0.976)	(4.655)	(5.512)		(0.826)
z_{it-1}	-0.033		-0.035	-0.001	-0.008		-0.047*	-0.004	0.0004		-0.045	-0.004
	(0.022)		(0.022)	(0.003)	(0.024)		(0.024)	(0.003)	(0.024)		(0.024)	(0.003)
$z_{it-1} * s_{it-1}$	-0.021*		0.078*	-0.0008	-0.018*		0.052*	0.0003	-0.013		0.047	0.0006
	(0.008)		(0.032)	(0.002)	(0.008)		(0.025)	(0.002)	(0.008)		(0.025)	(0.001)
y_{it-1}		-0.002	-0.031	0.008**		0.002	0.015	0.009**		0.004	0.026	0.008**
		(0.022)	(0.021)	(0.002)		(0.002)	(0.018)	(0.003)		(0.020)	(0.018)	(0.003)
$y_{it-1} * s_{it-1}$		-0.007*	-0.080*	0.002		-0.010	-0.051*	-0.001		-0.013	-0.046*	-0.003
		(0.010)	(0.032)	(0.002)		(0.009)	(0.022)	(0.002)		(0.010)	(0.022)	(0.002)
s_{it-1}	0.347*	0.066	0.094	-0.018	0.327*	0.098	0.034	0.011	0.253	0.148	0.014	0.029
	(0.144)	(0.159)	(0.187)	(0.018)	(0.140)	(0.154)	(0.139)	(0.016)	(0.140)	(0.158)	(0.145)	(0.017)
R^2 (%)	21.278	22.562	44.474	16.184	25.079	24.247	48.438	20.665	26.730	27.265	50.295	30.990
Adj. R^2 (%)	15.715	17.089	40.579	10.304	19.416	18.521	44.567	14.709	21.192	21.767	46.564	25.809

Table 7: **Robustness of the solvency-liquidity nexus to common factors.** Estimates from pooled OLS regression with bank dummies, time trends, heterogeneous AR parameters and state variable $s_{it} = 1_{\{SRISK_{it}>0\}}$. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, $(NI/TA)_{it} = NetIncome_{it}/TotalAssets_{it}$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. No Common Factor: regression without common factors (eq. (5)). Common Factors: regression with all (lagged) common factors of Table 6 (eq. (8)). Common Correlated Effects: regression with common correlated effects (eq. (9)). Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks. SRISK is the expected capital shortfall of the bank in a crisis.

Dep. variable:	dY_{it}	dZ_{it}	y_{it}	z_{it}	$(\mathrm{NI/TA})_{it}$	$(\mathrm{SRISK/TA})_{it}$
$(\mathrm{SRISK/TA})_{it-1}$	-0.013	-0.039	-1.059**	-0.038	-2.241**	
	(0.024)	(0.038)	(0.235)	(0.118)	(0.282)	
$(\mathrm{NI/TA})_{it-1}$	-0.870	0.290	2.313	-4.185		-1.211**
	(0.592)	(0.508)	(2.232)	(2.348)		(0.386)
z_{it-1}	-0.035**	-0.006	-0.034		0.162	-0.002
	(0.005)	(0.006)	(0.024)		(0.162)	(0.002)
y_{it-1}	-0.0004	-0.018**		-0.002	-0.023	0.008**
	(0.006)	(0.006)		(0.022)	(0.021)	(0.002)
dZ_{it-1}	0.101*		0.004	-0.110	-0.103	0.014
	(0.046)		(0.109)	(0.116)	(0.145)	(0.012)
dY_{it-1}		-0.104*	-0.137	0.157	0.254	-0.002
		(0.052)	(0.199)	(0.096)	(0.224)	(0.011)
R^2 (%)	11.319	12.008	21.047	22.411	42.099	15.837
Adj. R^2 (%)	5.197	5.934	15.554	17.013	38.099	10.024

Table 8: Estimates from pooled OLS regression with bank dummies, time trends and heterogeneous AR parameters. Dependent variables: $dY_{it} = \ln(LTDebt_{it}/LTDebt_{it-1})$, $dZ_{it} = \ln(LTAssets_{it}/LTAssets_{it-1})$, $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, $(NI/TA)_{it} = NetIncome_{it}/TotalAssets_{it}$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks. SRISK is the expected capital shortfall of the bank in a crisis.

PANEL A: Forecasting the short-term debt

Trend assumption	AR	VAR	INT	CF	$\triangle$RMSFE(SRISK)	$\triangle$RMSFE(NI)	$\triangle$RMSFE(STA)
heterogeneous trends	18567	16338	16267	**11939**	1871	-236	451
homogenous trend	10239	10577	**7943**	10753	813	-519	-198
no trend	8438	7943	**6801**	9046	1165	-185	-78
trend break	10038	8295	**7581**	12986	1252	-43	-148

PANEL B: Forecasting the short-term assets

Trend assumption	AR	VAR	INT	CF	$\triangle$RMSFE(SRISK)	$\triangle$RMSFE(NI)	$\triangle$RMSFE(STA)
heterogeneous trends	**13079**	13817	13596	15011	-113	84	-802
homogenous trend	**13477**	13828	13570	14381	45	-127	-228
no trend	14632	15349	14483	**14176**	370	-192	-651
trend break	13235	13108	**12988**	13985	-60	-101	264

PANEL C: Forecasting the liquid asset shortfall (whole sample)

Trend assumption	AR	VAR	INT	CF	$\triangle$RMSFE(SRISK)	$\triangle$RMSFE(NI)
heterogeneous trends	19834	17374	15673	**13426**	1638	-301
homogenous trend	15737	18475	16891	**15244**	370	-791
no trend	15999	17172	15952	**14915**	1629	-576
trend break	14353	14159	**13993**	15782	225	-321

PANEL D: Forecasting the liquid asset shortfall of adequately capitalized banks ($SRISK_{it} \leq 0$)

Trend assumption	AR	VAR	INT	CF	$\triangle$RMSFE(SRISK)	$\triangle$RMSFE(NI)
heterogeneous trends	7702	6443	6992	**4927**	87	-27
homogenous trend	**5294**	6003	6672	5338	-185	-84
no trend	**5297**	6117	6666	5725	-58	-54
trend break	**4431**	5374	5654	5081	-236	-49

PANEL E: Forecasting the liquid asset shortfall of capital-constrained banks ($SRISK_{it} > 0$)

Trend assumption	AR	VAR	INT	CF	$\triangle$RMSFE(SRISK)	$\triangle$RMSFE(NI)
heterogeneous trends	25413	22329	19858	**17267**	2214	-406
homogenous trend	20337	23916	21615	**19658**	536	-1057
no trend	20692	22122	20326	**19125**	2226	-774
trend break	18624	18170	**17877**	20439	358	-429

Table 9: **Forecasting the short-term balance sheet**. Root Mean Square Forecasting Error (RMSFE): one-step ahead forecasting over 2011. Fixed estimation sample (2000-2010), information updated each quarter. AR: univariate autoregressive model. VAR: panel VAR model (eq. (4)). INT: panel VAR with interaction with SRISK (eq. (5)). CF: panel VAR with interaction with SRISK and common factors (eq. (8)). $\triangle$RMSE(x) is the increase in RMSE when variable x is not included in the VAR model. Liquid asset shortfall = STDebt - STAssets. In bold: minimum RMSFE for each line (trend assumption).

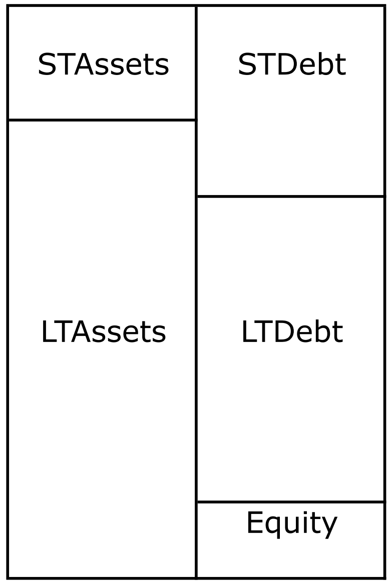

Figure 1: Simplified balance sheet. Liquid asset shortfall$_{it}$ $= STDebt_{it} - STAssets_{it}$. Capital shortfall$_{it}$ $= k * (STAssets_{it} + LTAssets_{it}) - Equity_{it}$. Expected capital shortfall in a crisis $SRISK_{it} = \mathrm{E}\left[k * (STAssets_{it+h} + LTAssets_{it+h}) - Equity_{it+h} | crisis_{t+h}\right] = k*(LTDebt_{it} + STDebt_{it}) - (1-k) * Equity_{it} * (1 + \mathrm{E}(R_{it+h}|crisis_{t+h}))$, where k is the prudential capital ratio (8%).

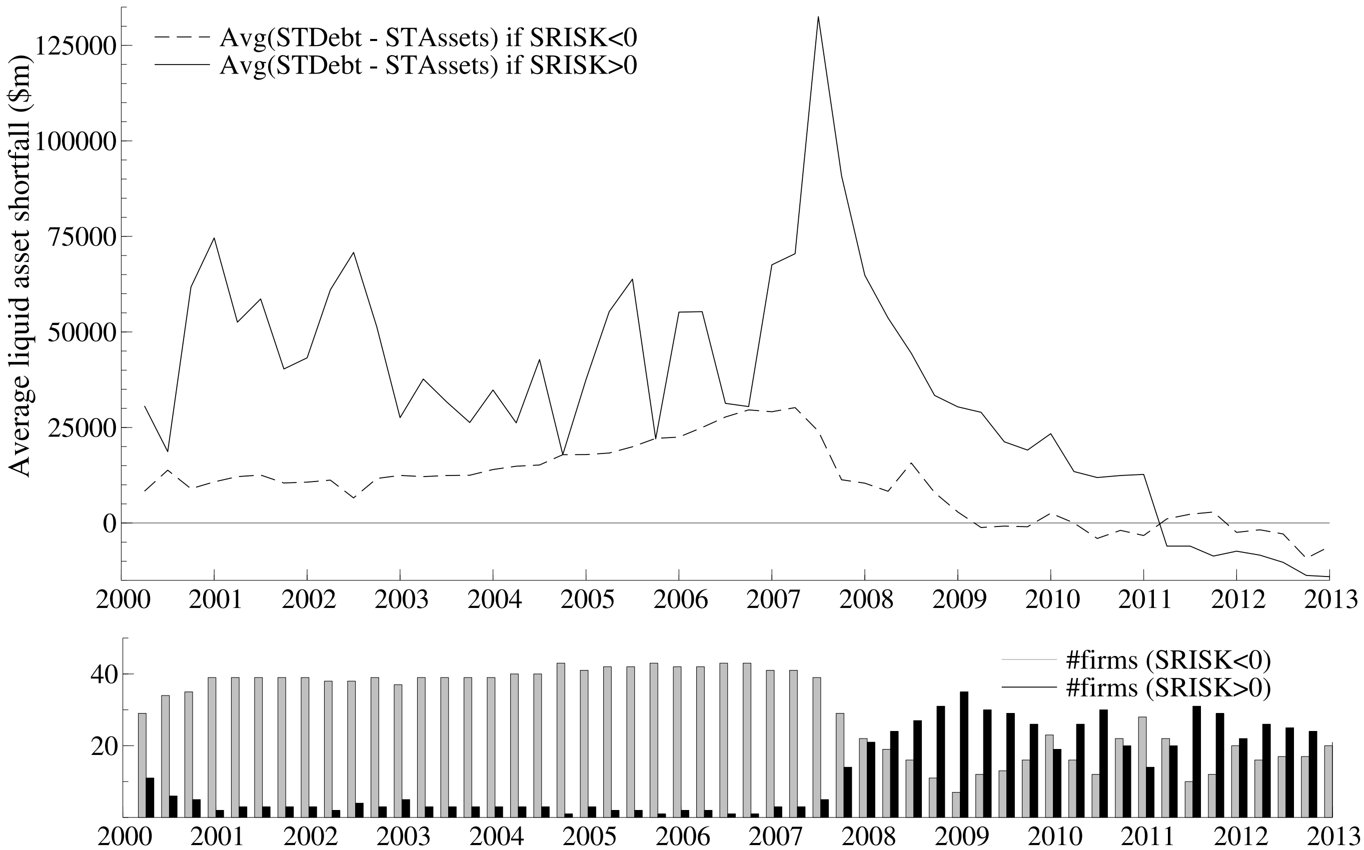

Figure 2: Cross-sectional average of the liquid asset shortfall of capital-constrained banks (black line) vs. cross-sectional average of the liquid asset shortfall of adequately capitalized banks (dashed line). Liquid asset shortfall = Short-term debt - Short-term assets ($m). "Adequately capitalized" means $SRISK_{it} \leq 0$.

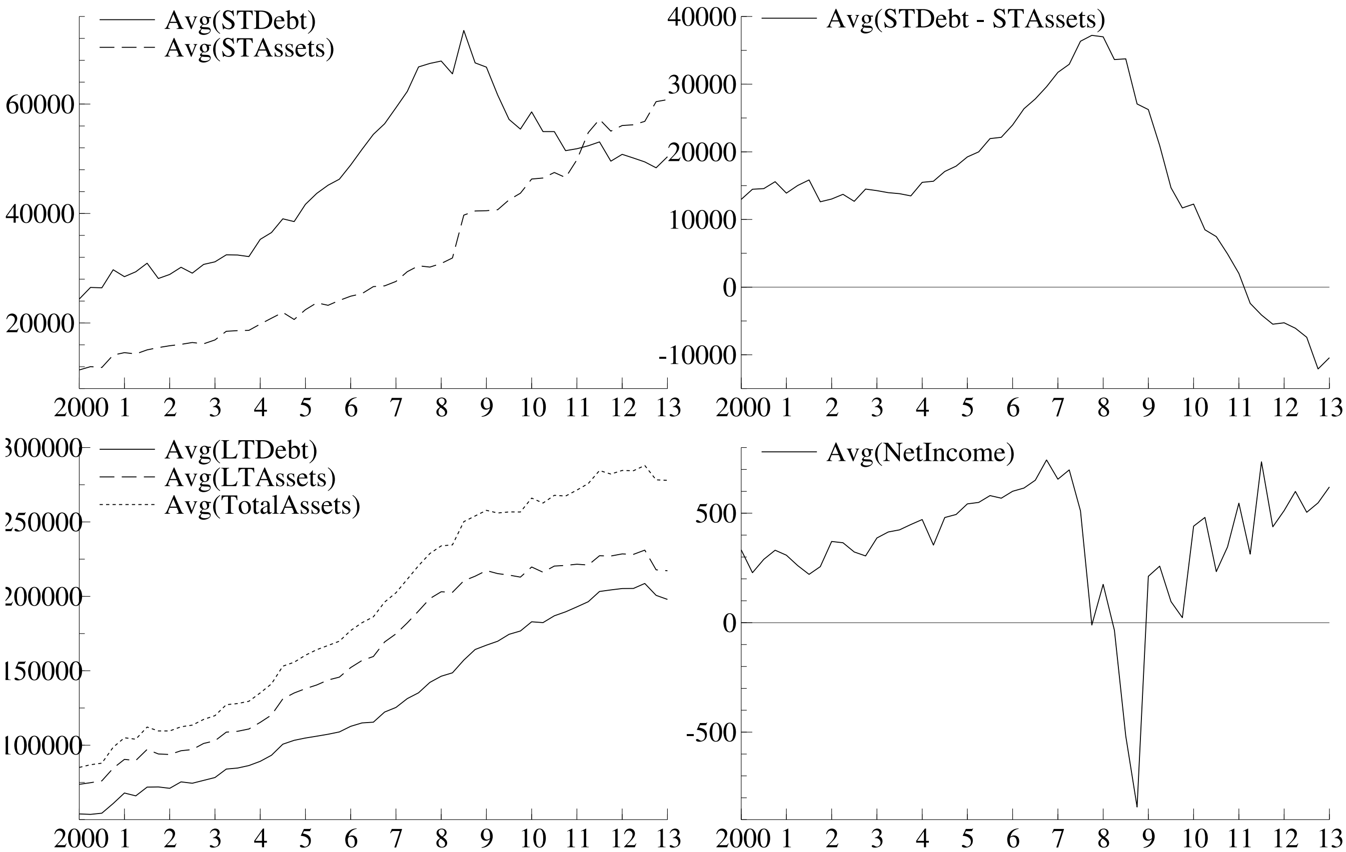

Figure 3: Cross-sectional averages of the balance sheet (in $m): short-term debt and short-term assets (top-left panel), difference between short-term debt and short-term assets (top-right panel), total assets and long-term balance sheet (bottom-left panel), net income (bottom-right panel).

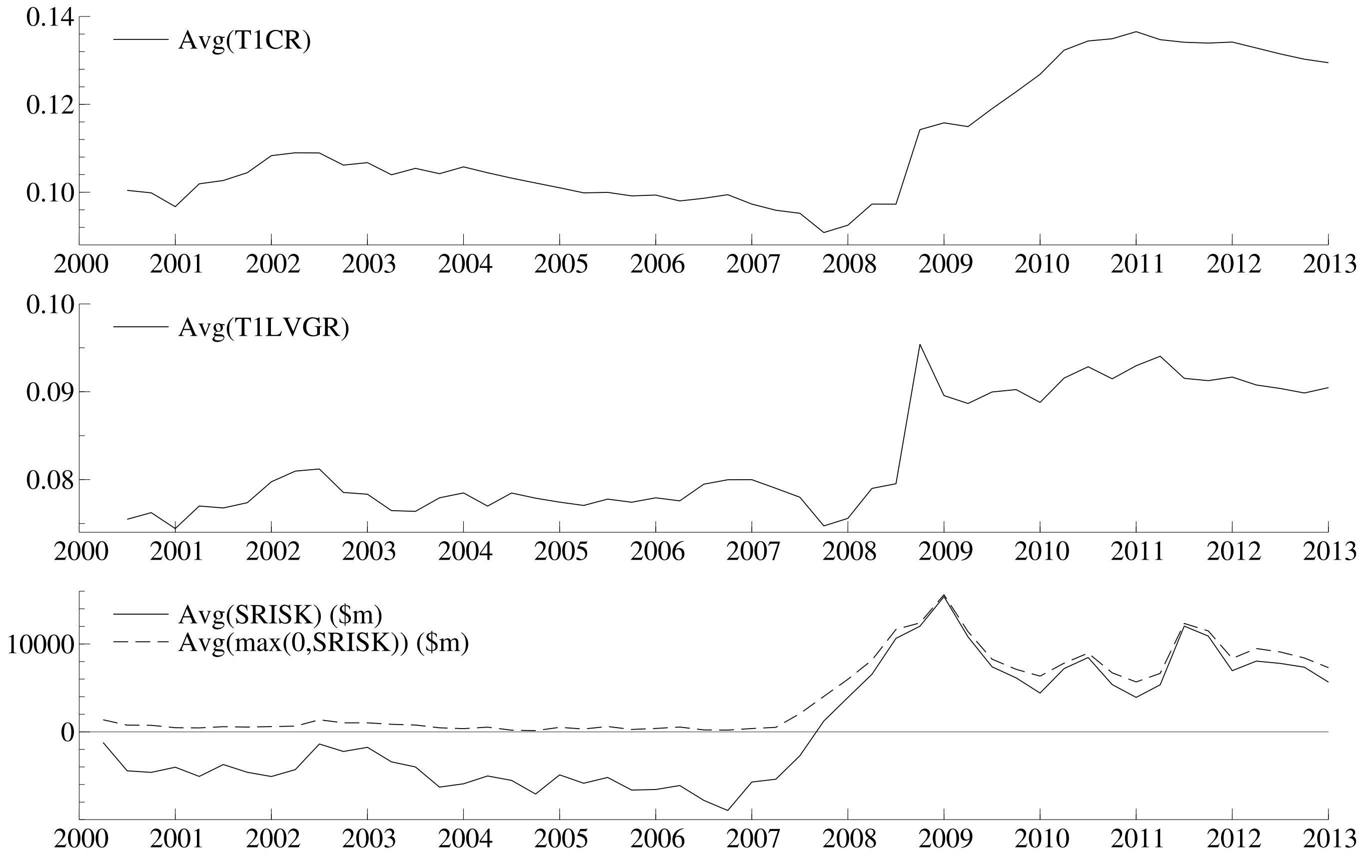

Figure 4: Cross-sectional averages of solvency risk measures. T1CR is the Tier 1 common capital ratio (Tier 1 common capital divided by risk-weighted assets); T1LVGR is the Tier 1 leverage ratio (Tier 1 capital divided by total assets); SRISK is the expected capital shortfall in a crisis.

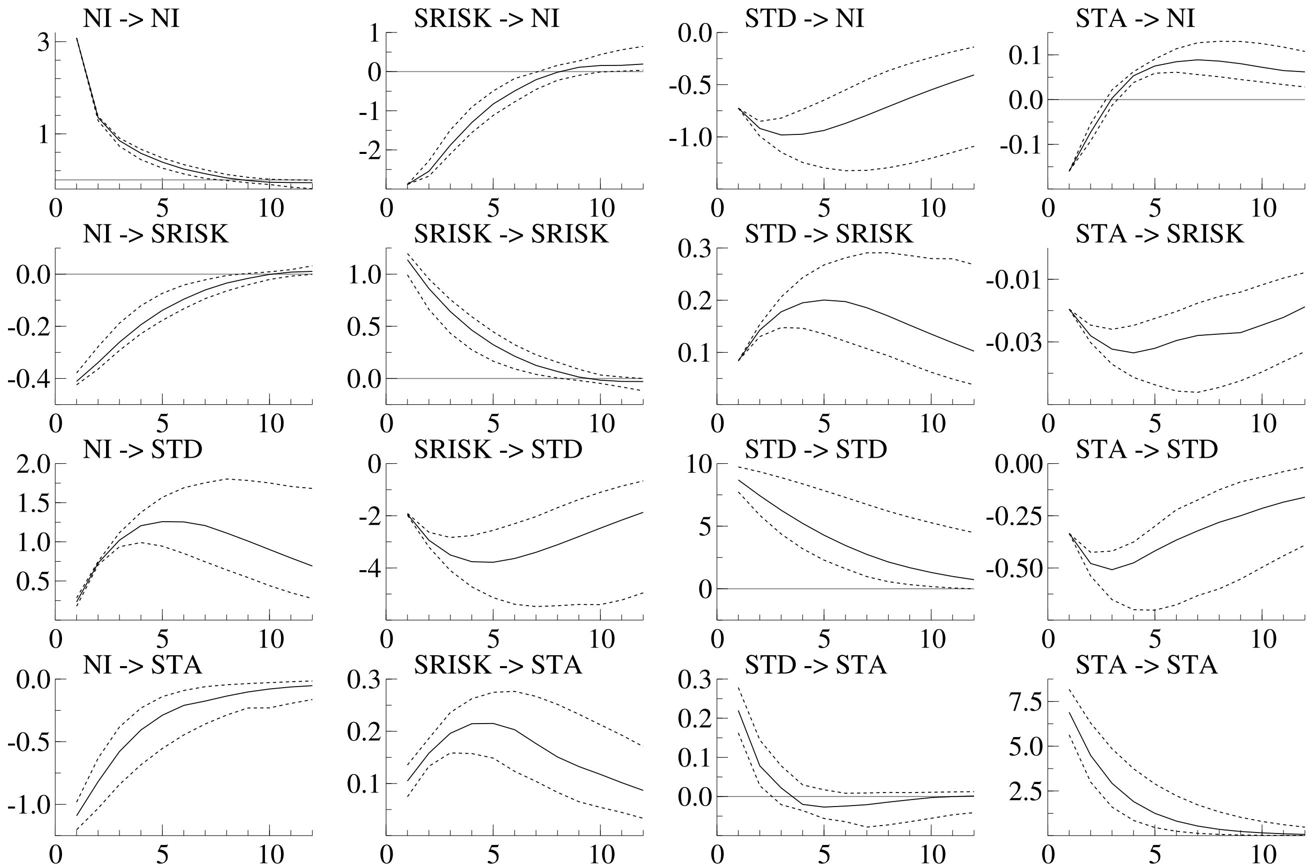

Figure 5: Impulse response functions. Median impulse response function (black lines) between the 25% and 75% impulse response quantiles (dotted lines).

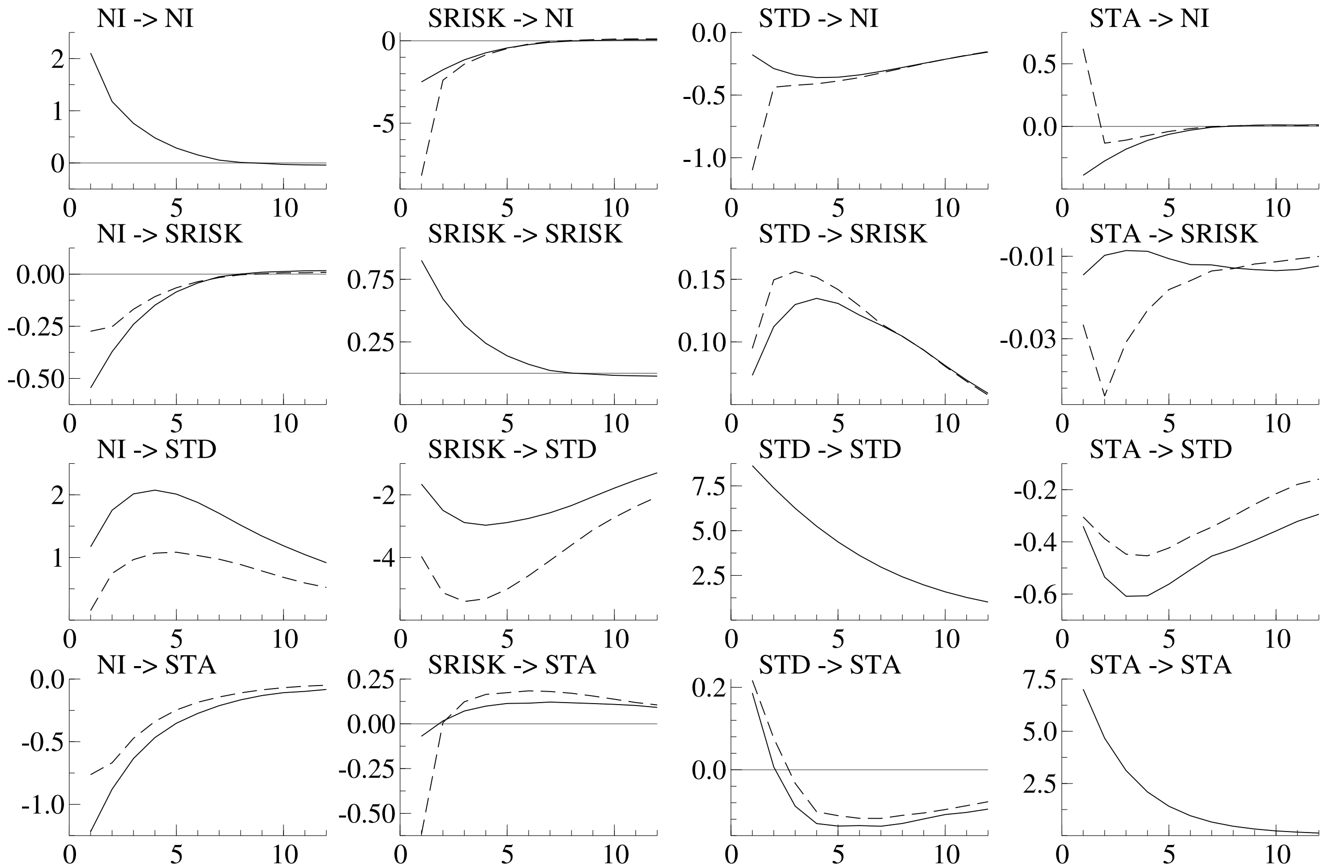

Figure 6: Impulse response functions with SRISK as a state variable (eq. (5)). Median impulse response function when $SRISK_{it} \leq 0$ (black line) and median impulse response function when $SRISK_{it} > 0$ (dashed line).

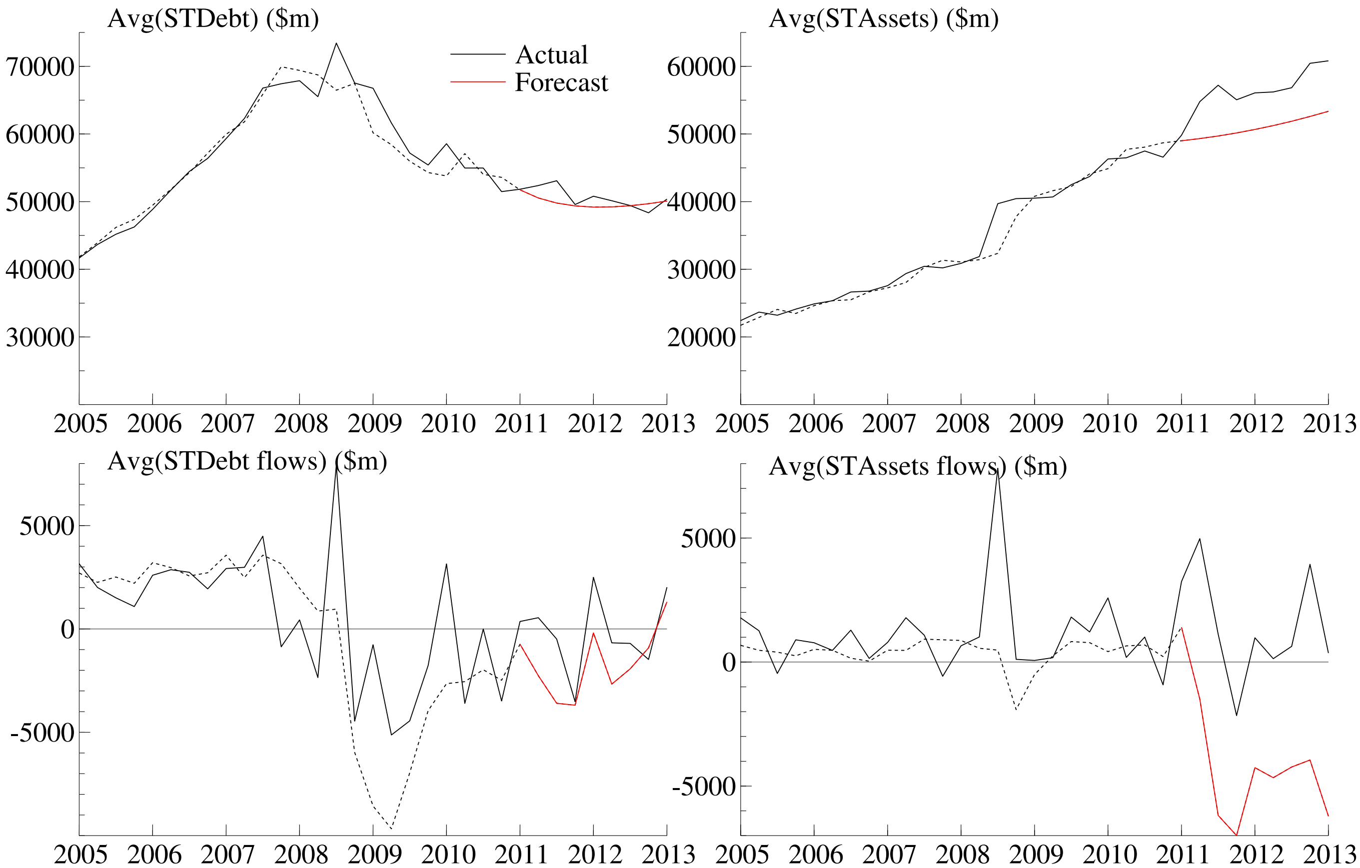

Figure 7: Forecasting the short-term balance sheet over 2011Q1-2013Q1: dynamic forecasts (panel VAR with SRISK as a state variable (eq. (5)), break in trend).

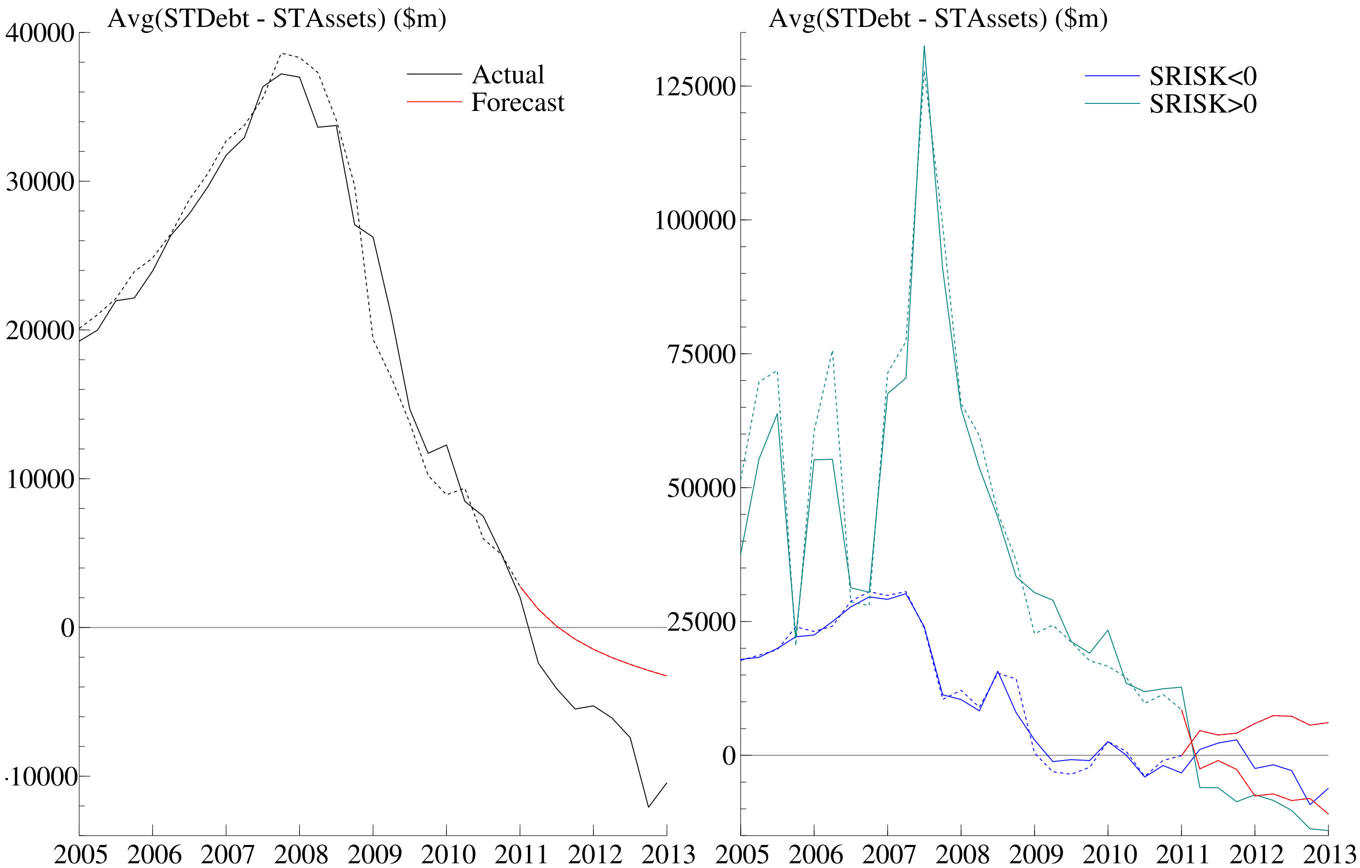

Figure 8: Forecasting the Liquid Asset Shortfall over 2011Q1-2013Q1: dynamic forecasts (panel VAR with SRISK as a state variable (eq. (5)), break in trend).

Appendix

A Short-term debt and short-term assets composition

Composition of the short term debt estimate (SNL definitions):

- Fed funds purchased: The gross dollar amount of funds borrowed in the form of immediately available funds under agreements or contracts that mature in one business day or roll over under a continuing contract, regardless of the nature of the transaction or the collateral involved. Includes securities sold under agreements to repurchase that involve the receipt of immediately available funds and mature in one business day or roll over under a continuing contract.

- Repurchase agreements: The gross dollar amount of security repurchase agreements that mature in more than one business day, other than securities sold under repurchase agreements to maturity, but including sales of participations in pools of securities that mature in more than one business day.

- Brokered Deposits ($<$ \$100K, maturity $\leq$ 1 Year): Brokered deposits issued in denominations of less than \$100,000 with a remaining maturity of one year or less and are held in domestic offices of commercial banks or other depository institutions that are subsidiaries of the reporting bank holding company. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a brokered deposit.

- Time Deposits ($\geq$ \$100K, maturity $\leq$ 1Year): Time deposits issued in denominations of \$100,000 or more with a remaining maturity of one year or less. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a time deposit.

- Foreign Office Time Deposits (maturity $\leq$ 1Year): All time deposits in foreign offices with remaining maturities of one year or less. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a time deposit.

- Commercial Paper: The total amount outstanding of commercial paper issued by the reporting bank holding company or its subsidiaries.

- Other borrowed money: The total amount of money borrowed by the consolidated bank holding company with a remaining maturity of one year or less. For purposes of this item, remaining maturity is the amount of time remaining from the report date until the final contractual maturity of a borrowing without regard to the borrowing's repayment schedule, if any. Includes the dollar amount outstanding of all interest-bearing demand notes issued to the U.S. Treasury by the depository institutions that are consolidated subsidiaries of the reporting bank holding company. Also includes mortgage indebtedness and obligations under capitalized leases with a remaining maturity of one year or less. Also includes the total amount of money borrowed with a remaining maturity of one year or less: (1) on its promissory notes; (2) on notes and bills rediscounted; (3) on loans sold under repurchase agreements that mature in more than one business day; (4) by the creation of due bills representing the bank holding company's receipt of payment and similar instruments, whether collateralized or uncollateralized; (5) from Federal Reserve Banks; (6) by overdrawing 'due from' balances with depository institutions, except overdrafts arising in connection with checks or drafts drawn by subsidiary depository institutions of the reporting bank holding company and drawn on, or payable at or through, another depository institution either on a zero-balance account or on an account that is not routinely maintained with sufficient balances to cover checks or drafts drawn in the normal course of business during the period until the amount of the checks or drafts is remitted to the other depository institution; (7) on purchases of so-called 'term federal funds'; and (8) on any other obligation for the purpose of borrowing money that has a remaining maturity of one year or less and that is not reported elsewhere.

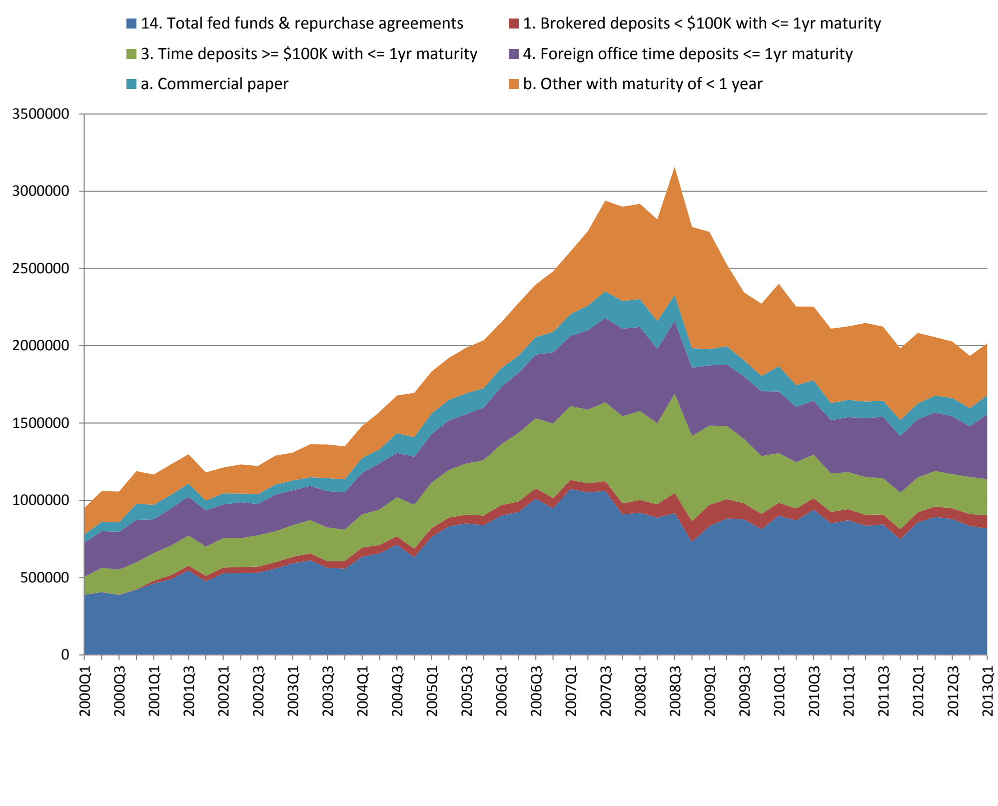

Figure 9: Short term debt composition ($m) - 44 BHCs

Composition of the short term assets estimate (SNL definitions):

- Cash & Non interest-bearing Deposits: The total of all noninterest-bearing balances due from depository institutions, currency and coin, cash items in process of collection, and unposted debits. Includes balances due from banks in the U.S., banks in foreign countries and foreign central banks, foreign branches of other U.S. banks, Federal Home Loan Banks, and Federal Reserve Banks.

- Total Interest-bearing Balances: The total of all interest-bearing balances due from depository institutions and foreign central banks that are held in offices of the bank holding company or its consolidated subsidiaries.

- Fed Funds Sold: The gross dollar amount of funds lent in the form of immediately available funds under agreements or contracts that mature in one business day or roll over under a continuing contract. Includes securities purchased under agreements to resell that involve the receipt of immediately available funds and mature in one business day or roll over under a continuing contract.

- Reverse Repurchases Agreements: The gross dollar amount of security resale agreements that mature in more than one business day, other than securities purchased under resale agreements to maturity, and of purchases of participations in pools of securities that mature in more than one business day.

- Debt Securities Maturing or Repriced (maturity $\leq$ 1Year): All securities held by the consolidated bank holding company with a remaining maturity or amount of time remaining until next repricing date of one year or less. Held-to-maturity securities are reported at amortized cost and available-for-sale securities are reported at fair value. Remaining maturity is the amount of time remaining from the report date until the final contractual maturity of the instrument without regard to the instrument's repayment schedule. Next repricing date is the date the interest rate on a floating rate debt security can next change. (Y9 Line Item: BHCK0383)

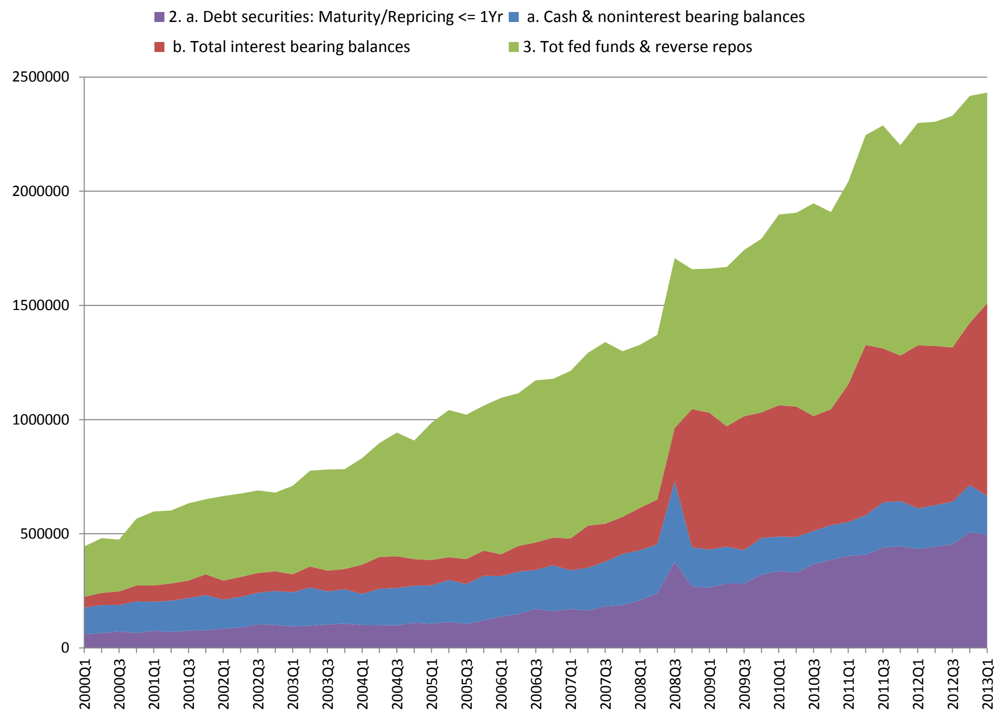

Figure 10: Short-term assets composition ($m) - 44 BHCs

B Stationarity of balance sheet aggregates

To test for the stationarity of y_{it}, z_{it} and other balance sheet quantities, I apply the unit root test of Pesaran (2007) (CIPS) robust to cross-sectional dependence between individuals in the panel data set. The the null hypothesis is $H_0 : \alpha_{21} = \alpha_{22} = ... = \alpha_{2N} = 0$, $i = 1, 2, ..., N$ (unit root), and the alternative $H_a : \alpha_{21} < 0, ..., \alpha_{2N_0} < 0$, $N_0 \leq N$(a significant fraction of the panel is stationary). The regression for the CIPS unit root test is

$$dy_{it} = \alpha_{0i} + \alpha_{1i} dy_{it-1} + \alpha_{2i} y_{it-1} + a_i d\bar{y}_t + b_i \bar{y}_{t-1} + c_i d\bar{y}_{t-1} + \theta_i t + \varepsilon_{it}, \quad (10)$$

where $d\bar{y}_t = N^{-1} \sum_{i=1}^{N} dy_{it}$, $\bar{y}_t = N^{-1} \sum_{i=1}^{N} y_{it}$. The CIPS test statistics are reported in Table 10 for both cases with and without trend (i.e. $\theta_i = 0$, $\forall i$). Based on the CIPS statistics and given the critical values of the CADF distribution, y_{it} is stationary only when the regression includes a trend. The hypothesis of the absence of a trend is rejected based on a Wald test, therefore y_{it} is considered stationary in the rest of the paper.

On the other bank sheet aggregates, the UR hypothesis is not rejected for the size (logarithm of total assets) and the long-term balance sheet (logarithm of long-term assets Z_{it} and long-term debt Y_{it}). Finally, the short-term assets, $SRISK$ and the net income divided by total assets are stationary with this test.

	Intercept only		Intercept and trend	
	CIPS	CIPS^b	CIPS	CIPS^b
y_{it}	**-2.064**	**-1.922**	-2.725	-2.660
z_{it}	-2.538	-2.545	-2.798	-2.849
NI_{it}/TA_{it}	-3.541	-3.831	-4.101	-4.381
Y_{it}	**-2.071**	-2.199	**-2.274**	**-2.468**
Z_{it}	**-1.954**	**-2.098**	**-2.449**	**-2.584**
$\log(TA_{it})$	**-1.709**	**-1.932**	**-2.163**	**-2.336**
$SRISK_{it}/TA_{it}$	-2.579	-2.434	-2.951	-2.989

Table 10: Panel UR tests: CIPS statistics. CADF 5% critical values: -2.11 (intercept only), -2.60 (intercept and trend). CIPS^b is the CIPS statistic based on a balanced panel dataset. $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, $Y_{it} = \ln(LTDebt_{it})$, $Z_{it} = \ln(LTAssets_{it})$, NI_{it}: net income, TA_{it}: total assets.

C Robustness checks

C.1 Period dummies

Dep. variable:	y_{it}	z_{it}	$(NI/TA)_{it}$	$(SRISK/TA)_{it}$	y_{it}	z_{it}	$(NI/TA)_{it}$	$(SRISK/TA)_{it}$
$(SRISK/TA)_{it-1}$	-1.063**	-0.028	-2.225**		-0.623	-0.108	-2.033**	
	(0.245)	(0.118)	(0.301)		(0.357)	(0.178)	(0.217)	
$(SRISK/TA)_{it-1} * c_t$					-0.606**	0.188	-0.321	
					(0.231)	(0.167)	(0.182)	
$(SRISK/TA)_{it-1} * pc_t$					-0.091	-0.298	0.137	
					(0.383)	(0.262)	(0.194)	
$(NI/TA)_{it-1}$	2.354	-4.228		-1.217**	25.036**	-7.046		-7.529**
	(2.278)	(2.331)		(0.389)	(7.838)	(5.344)		(2.011)
$(NI/TA)_{it-1} * c_t$					-24.850**	5.882		6.355**
					(8.248)	(6.315)		(1.576)
$(NI/TA)_{it-1} * pc_t$					-20.939	-8.164		9.165**
					(12.332)	(7.475)		(2.463)
z_{it-1}	-0.038		-0.015	-0.002	-0.012		-0.033	0.001
	(0.023)		(0.020)	(0.002)	(0.024)		(0.024)	(0.002)
$z_{it-1} * c_t$					-0.003		0.018	-0.006**
					(0.011)		(0.033)	(0.002)
$z_{it-1} * pc_t$					-0.008		0.003	-0.001
					(0.020)		(0.030)	(0.003)
y_{it-1}		-0.004	-0.067**	0.008**		0.002	0.015	0.008*
		(0.021)	(0.026)	(0.002)		(0.023)	(0.017)	(0.003)
$y_{it-1} * c_t$						0.011	-0.048	0.007*
						(0.014)	(0.034)	(0.003)
$y_{it-1} * pc_t$						0.009	-0.059*	0.00001
						(0.022)	(0.029)	(0.004)
c_t					0.114	-0.151	0.360	-0.017
					(0.168)	(0.241)	(0.227)	(0.028)
pc_t					0.023	-0.042	0.904**	0.005
					(0.296)	(0.383)	(0.237)	(0.034)
R^2 (%)	20.870	22.318	41.925	15.787	24.877	22.956	44.361	25.551
Adj. R^2 (%)	15.450	16.997	37.977	10.062	19.405	17.343	40.336	20.165

Table 11: Estimates from pooled OLS regression with bank dummies, time trends and heterogeneous AR parameters. Dependent variables: $y_{it} = \ln(STDebt_{it})$, $z_{it} = \ln(STAssets_{it})$, $(NI/TA)_{it} = NetIncome_{it}/TotalAssets_{it}$, $(SRISK/TA)_{it} = SRISK_{it}/TotalAssets_{it}$. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks. SRISK is the expected capital shortfall of the bank in a crisis.

C.2 Short-term debt components

Dep. variable:	y_{it}	FFRepo	Br Dep	Time Dep	For Dep	ComPaper	OtherBor
$(\text{SRISK}/\text{TA})_{it-1}$	-1.063**	-1.217**	0.147	-0.363*	-1.155*	-2.330**	-0.281
	(0.245)	(0.403)	(0.518)	(0.175)	(0.531)	(0.364)	(0.377)
$(\text{NI}/\text{TA})_{it-1}$	2.354	0.152	-11.694	-1.660	10.880	17.540	3.249
	(2.278)	(2.437)	(8.376)	(4.733)	(6.282)	(10.392)	(9.375)
z_{it-1}	-0.038	0.015	-0.028	-0.046*	-0.191*	-0.091	-0.233**
	(0.023)	(0.051)	(0.096)	(0.019)	(0.093)	(0.083)	(0.079)
# obs.	2107	1979	950	2096	1337	966	2035
# banks	44	44	40	44	34	27	44
R^2 (%)	20.870	19.723	23.649	34.947	38.600	25.330	22.656
Adj. R^2 (%)	15.450	13.843	12.279	30.459	33.355	18.187	17.152

Table 12: Estimates from pooled OLS regression with bank dummies, time trends and heterogeneous AR parameters. Dependent variables: log of the different components of the short term debt (see definitions in Appendix A): Fed funds and Repos (FFRepo), Brokered Deposits (Br Dep), uninsured Time Deposits (Time Dep), Foreign Deposits (For Dep), Commercial Papers (ComPaper) and Other Borrowed Money (OtherBor). Robust standard errors in parentheses. Robust standard errors in parentheses. * significant parameter at 5%; ** at 1%. Sample: 2107 panel obs. over 2000Q1-2013Q1 (unbalanced), 44 banks. SRISK is the expected capital shortfall of the bank in a crisis.

D Sample of banks

Name	Ticker	SNL ID	RSSD ID	Industry	Market Cap
American Express Company	AXP	102700	1275216	Specialty Lender	60,834
Bank of America Corporation	BAC	100369	1073757	Bank	183,125
The Bank of New York Mellon Corporation	BK	100144	3587146	Bank	55,522
BB&T Corporation	BBT	100438	1074156	Bank	16,852
Capital One Financial Corp.	COF	103239	2277860	Bank	18,215
Citigroup, Inc.	C	4041896	1951350	Bank	146,644
Fifth Third Bancorp	FITB	100260	1070345	Bank	13,386
The Goldman Sachs Group, Inc.	GS	4039450	2380443	Broker Dealer	85,520
JPMorgan Chase & Co.	JPM	100201	1039502	Bank	146,622
KeyCorp	KEY	100334	1068025	Bank	9,117
MetLife, Inc.	MET	4051708	2945824	Insurance	45,636
Morgan Stanley	MS	103042	2162966	Broker Dealer	56,362
The PNC Financial Services Group, Inc.	PNC	100406	1069778	Bank	22,355
Regions Financial Corporation	RF	100233	3242838	Bank	16,439
State Street Corporation	STT	100447	1111435	Bank	31,360
SunTrust Banks, Inc.	STI	100449	1131787	Bank	21,756
U.S. Bancorp	USB	4047176	1119794	Bank	54,804
Wells Fargo & Company	WFC	100382	1120754	Bank	101,269
Franklin Resources Inc.	BEN	102719	1246216	Asset Manager	28,037
Commerce Bancshares, Inc.	CBSH	100184	2815235	Bank	3,229
CIT Group Inc.	CIT	102820	1036967	Specialty Lender	NA
Comerica Incorporated	CMA	100206	1029259	Bank	6,574
Huntington Bancshares Incorporated	HBAN	100307	1068191	Bank	5,401
Marshall & Ilsley	MI	100364	3594612	Bank	7,086
M&T Bank Corporation	MTB	100253	1037003	Bank	8,708
National City Corp.	NCC	100378	1069125	Bank	10,433
Northern Trust Corporation	NTRS	100386	1199611	Bank	16,843
New York Community Bancorp Inc.	NYCB	1024119	2132932	Savings/Thrift/Mutual	5,689
The Charles Schwab Corporation	SCHW	102775	1026632	Broker Dealer	29,547
Synovus Financial Corporation	SNV	100440	1078846	Bank	7,943
UnionBanCal Corporation	UB	1022285	1378434	Bank	6,776
Wachovia Bank	WB	100293	1073551	Bank	75,122
Zions Bancorp.	ZION	100501	1027004	Bank	4,995
Associated Banc-Corp	ASBC	100135	1199563	Bank	3,442
Bank of Hawaii Corporation	BOH	100161	1025309	Bank	2,506
BOK Financial Corporation	BOKF	100003	1883693	Bank	3,471
Popular, Inc.	BPOP	100165	2138466	Bank	2,971
Cullen/Frost Bankers, Inc.	CFR	100196	1102367	Bank	2,963

Table 13: Sample 1/2. Market capitalization in $m (Dec 30, 2007).

Name	Ticker	SNL ID	RSSD ID	Industry	Market Cap
City National Corporation	CYN	100225	1131004	Bank	2,866
Discover Financial Services	DFS	4096334	3846375	Specialty Lender	NA
East West Bancorp, Inc.	EWBC	4040606	2734233	Bank	1,527
First Citizens BancShares, Inc.	FCNCA	100247	1105470	Bank	1,619
First Horizon National Corporation	FHN	100292	1094640	Bank	2,294
Fulton Financial Corporation	FULT	100294	1117129	Bank	1,946
Hancock Holding Company	HBHC	100308	1086533	Bank	1,207
Prosperity Bancshares, Inc.	PB	1018962	1109599	Bank	1,297
SVB Financial Group	SIVB	100433	1031449	Bank	1,673
TCF Financial Corporation	TCB	102002	2389941	Bank	2,272
Webster Financial Corporation	WBS	102030	1145476	Bank	1,710

Table 14: Sample 2/2. Market capitalization in $m (Dec 30, 2007).