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Short-Term Debt and Bank Risk

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Abstract

The extant literature suggests that one of the main causes of the recent financial crisis was the excessive use of short-term debt by banks. Using a large sample of banks, we find that increases in repurchase agreements (repos) were recognized by external capital markets to increase bank risk in the pre-crisis period. In the crisis, we find a negative relationship between repos and risk. We attribute this result to evidence suggesting that "good" banks were able to continue funding their repos, whereas "bad" banks had to significantly decrease their repo funding.

I. Introduction

Many authors describing the recent financial crisis have highlighted the important role of short-term debt in creating excessive bank risk (see, e.g., Bernanke (2008), Gorton (2009), Brunnermeier (2009), Shin (2009), and Krishnamurthy (2010)). Early theoretical literature has shown that short-term financing, in the form of the demand deposit contracts, can leave depositors vulnerable to runs (Bryant (1980), Diamond and Dybvig (1983), Allen and Gale (1998), Rochet and Vives (2004), and Goldstein and Pauzner (2005)). The solution to the bank run problem in many of these models is federal deposit insurance. More recently, He and Xiong (2012a), (2012b) show that short-term debt instruments, such as repurchase agreements ("repos") and commercial paper, can incentivize creditors to run due to rollover risk. Brunnermeier and Oehmke (2013) study the conflict between long- and short-term creditors and show that this conflict can motivate all creditors to demand short-term debt. Banks are caught in a liquidity squeeze when they have to rollover "shadow" short-term debt instruments, which

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have no federal deposit insurance.[1] The demand for liquidity strains holdings in liquid assets and forces their liquidation at fire-sale prices. Acharya, Gale, and Yorulmazer (2011) show that a market freeze can occur if rollover frequency is sufficiently high. Acharya and Viswanathan (2011) show that the extent to which financial firms face de-leveraging or fire sales is a function of their reliance on short-term debt.

Using a comprehensive sample of 216 publicly traded U.S. bank holding companies (BHCs) for the period from 2002 through 2009, this paper empirically examines the relationship, if any, between short-term funding and bank risk. Given that the crisis hit noncommercial investment banks, such as Lehman Brothers and Bear Stearns, more severely, any result that we find is a lower bound on the relationship between short-term debt and a financial institution's risk. Specifically, this paper empirically examines the following questions: i) Before the crisis, did the external capital markets know that increases in short-term funding increased bank risk or was it an unexpected shock? ii) Which type of short-term debt instrument (repos or commercial paper) increased bank risk in the pre-crisis period? iii) What happened to the relationship between bank risk and short-term debt during the crisis? iv) Did insufficient liquidity contribute to higher bank risk?

We find the following results:

i) We find that bank risk is higher when the fraction of debt (excluding demand deposits) in repos is higher in the pre-crisis period. No significant relationships are found for commercial paper, brokered deposits, and core deposits. These results are robust to including bank-level fixed effects to control for unobservable factors, quarterly dummy variables, and standard errors corrected for clustering at the firm and year levels. The importance of repos to increasing bank risk is consistent with the results of Gorton and Metrick (2012a), (2012b), which find that a significant "run" in the repo market contributed to the financial crisis.

ii) We find that holding more liquid assets does not allow banks to reduce their risk either in the pre-crisis or crisis period. These results are counter to the notion that liquid assets (i.e., cash and Treasury securities) provide a buffer against shocks, but they are consistent with those of Diamond and He (2014), which suggest that managers have incentives to divert their cash rather than to hold it for later periods.

iii) When we examine the crisis period, we find that the impact of repos actually decreased bank risk. We attribute this result to heterogeneity among repo users. Good banks (defined over the pre-crisis period) were able to continue funding their repos at the same level in the crisis when compared to the pre-crisis period. However, bad banks (defined over the pre-crisis period) had to decrease funding in repos during the crisis. This result holds whether bank quality in the pre-crisis period is proxied by Tobin's Q (defined as the sum of the market value of equity and book value of liabilities divided by assets) or ROA (defined as the ratio of net income to assets). We find that good (bad) banks have a negative (insignificant) repo–risk relationship in the crisis. These results are consistent with the interpretation that good quality banks were able to continue funding in the

[1]See Section II for the related theories of short-term debt and a detailed description of repos and commercial paper.

repo market during the crisis, while bad quality banks generally decreased their repo funding during the crisis.

iv) We examine if the change in repo funding from the pre-crisis to the crisis period is correlated with bank stock returns during the crisis. Fahlenbrach, Prilmeier, and Stulz (FPZ) (2012) find a positive relation between bank performance in 1998 and the stock returns in the crisis. We adopt their approach and find that an increase in repo financing is associated with higher returns during the crisis period, while controlling for performance in 1998. This is consistent with the idea that good banks that are able to obtain repo funding during the crisis are associated with higher stock returns.

The remainder of the paper is organized as follows: Section II describes the related literature on short-term debt and rollover risk. Section III provides the data and variables used in the study. Section IV presents our empirical tests and results, and Section V concludes.

II. Related Literature

In this section, we describe in more detail the related literature on short-term debt and bank risk. Brunnermeier (2009) is the first to describe the inability or difficulty for firms to refinance short-term debt as rollover risk. Purnanandam (2011) shows that the originate-to-distribute business model of banks along with asset securitization led to the origination of poor-quality loans and contributed to the housing market bubble. While it may be argued that asset securitization products can reduce liquidity risk through the utilization of special purpose vehicles, they are also used as collateral for short-term debt instruments such as repos and commercial paper. Gennaioli, Shleifer, and Vishny (2012) argue that investors and financial intermediaries neglected various risks associated with issuance of securitized assets and, in doing so, created excessive supply of such products. When these risks are revealed, these securities create freezes in the asset-backed commercial paper (ABCP) and repo markets and investors fly back to safety. Hanson, Shleifer, Stein, and Vishny (2014) demonstrate the fundamental difference between traditional banking and shadow banking. They show that traditional banking relies on combining stable funding on the liability side while holding relatively safe yet illiquid, long-term loans and securities. On the other hand, shadow banking creates claims by allowing investors an early exit option to seize assets and liquidate during downturns. This fundamental difference in risk and funding structure leaves shadow institutions more prone to runs and fire sales.

A number of articles have corroborated the perils of rollover risk associated with excessive short-term debt financing, which can lead to diminishing debt capacity (Acharya et al. (2011)), preemptive running by creditors (He and Xiong (2012a)), and exacerbating the debt-overhang problem (Diamond and He (2014)). In this paper, we focus primarily on the role of short-term debt instruments that have relatively shorter maturities than other forms of debt and, thus, need to be rolled over more frequently. Covitz, Liang, and Suarez (2013) suggest that more than half the daily issuance of ABCP have maturities of 1–4 days and the average maturity of outstanding commercial paper is about 30 days. Brunnermeier (2009) suggests that term repos (with a maturity of up to 3 months) remained at a relative fraction of total assets; however, overnight repos (with a maturity of 1 day) increased dramatically in the period leading up to the crisis. He and Xiong (2012b) show that the presence of certain forms of short-term debt, such as repos and commercial paper, amplifies the conflicts between debt and equity holders during distress.

A. Repurchase Agreements

A sale and repurchase agreement ("repo") is the sale of a financial asset to another party subject to an agreement by the seller to repurchase the asset at a pre-specified date and price. The market value of the securities purchased usually exceeds the value of the cash the borrower receives, and the difference (generally expressed as a percentage) is called the "margin" and measures the extent to which the loan is overcollateralized. The collateral used in repo transactions includes government securities, federal agency securities, mortgage-backed securities (MBS), asset-backed securities, money market instruments, and corporate debt or equity.

Gorton and Metrick (2012a) show that overreliance on repos, and the subsequent run in the repo market, was a main cause for the recent financial crisis. Gorton and Metrick (2012b) find that a significant run in the bilateral repo market was predominantly driven by the flight of domestic and off-shore hedge funds, foreign financial institutions, and other unregulated cash pools. Krishnamurthy, Nagel, and Orlov (2014) utilize data for repos between nonbank lenders and dealer banks and show that repos account for a small fraction of short-term funding of securitized assets. They find that ABCP accounted for a much larger magnitude of financing prior to the crisis and the contraction during the crisis. They also find that the contraction in repos disproportionately affected a few dealer banks. Copeland, Martin, and Walker (2014) find that the repo margins and funding amounts were stable during the crisis for tri-party repos.

In the model of debt capacity developed by Acharya et al. (2011), the underlying assumption is that debt with a shorter tenor than the firm's assets needs to be rolled over more frequently. High rollover frequency associated with short-term debt can lead to reduced debt capacity, which ultimately leads to a market freeze. Thus, the level of short-term debt, measured by rollover frequency, is expected to be positively related to rollover risk. Since a freeze in the market for repos is correlated with high repo haircuts, the authors show that repo haircuts rise in a deteriorating economy due to high repo frequency. Martin, Skeie, and von Thadden (2014) provide insights to the conditions in which repo funding may be unstable during times of stress. He and Xiong (2012a) show that rollover frequency is a factor that motivates maturing creditors to run even when the firm is still solvent.

B. Commercial Paper

Commercial paper consists of short-term negotiable promissory notes. Various other papers have examined ABCP issued by conduits for financial holding companies (Kacperczyk and Schnabl (2010)). Acharya, Schnabl, and Suarez (2013) find that banks provide guarantees to conduit investors and argue that banks use conduits for regulatory arbitrage. Covitz et al. (2013) find substantial runs in the ABCP market during the crisis using proprietary data from the Depository Trust and Clearing Corporation to examine the prices, quantities, and maturities of ABCP. In this study, we examine bank holding company–level commercial paper, as information at the conduit level is not available in our sample.

III. Data and Variables

A. Data

This study utilizes a list of BHCs obtained from the Federal Reserve Bank of New York's Center for Research in Security Prices (CRSP)–Federal Reserve Banks link.[2] Prior research in this field required hand-matched data based on an institution's name, which is prone to error and only utilizes the largest BHCs. This paper considers a broader set of firms from Standard Industrial Classification (SIC) codes 6000, 6011, 6020, 6021, 6022, 6025, 6030, 6035, 6036, 6211, 6331, 6411, 6710, 6711, and 6712. Daily stock returns and market returns are obtained from the CRSP daily file. Balance sheet and income statement data are obtained from the consolidated financial statements for BHCs or the FR Y-9C report. Data are obtained from 2002 to 2009.[3] Banks with information available on both CRSP and FR Y-9C are examined. The final sample consists of 216 BHCs. We do not include any investment banks.

Our analysis is conducted quarterly for the following reasons. First, the FR Y-9C data contain quarterly reports. Hence, analysis performed on a quarterly basis fully captures the effects of timing on the relationship between measures of short-term debt and bank risk. Second, using annual data limits the number of data points available for analysis.

B. Variables

We describe subsequently the construction of each variable used in our regressions, and the variable name from FR-Y 9C is given in brackets. Table 1 summarizes the description of each variable.

1. Risk

STANDARD_DEVIATION: Our main proxy for bank risk is the standard deviation of a bank's stock returns. This measure of risk has been used by Stiroh (2004), (2006), De Jonghe (2010), Laeven and Levine (2009), Saunders, Strock, and Travlos (1990), Pathan (2009), and Goetz et al. (2016) in the banking literature. Risk is measured as the standard deviation of daily stock returns in a quarter measured as a percentage. Daily returns are calculated as the natural logarithm of the ratio of the daily equity price series [$\ln(P_t/P_{t-1})$]. Note that risk is measured for the period (quarter) following financial statement measures.[4] If a firm

[2]This link matches regulatory entity codes and CRSP's permanent company identifier (PERMCO) for publicly traded banks and bank holding companies. For more information, see http://www.newyorkfed.org/research/banking_research/datasets.html.

[3]The year 2002 is chosen because it is the first year in which bank holding companies are required to report repo positions in the FR Y-9C report.

[4]The first FR Y-9C report of 2002 is on Mar. 31. Thus, the corresponding risk measures are for the 2nd quarter of 2002.

TABLE 1
Variable Definitions

Table 1 reports the definitions of the variables used in the study.

Variables	Description
Risk variables:	
STANDARD_DEVIATION	Standard deviation of daily returns in a quarter; returns are calculated as the natural logarithm of the ratio of the daily equity market price series ($\ln(P_t/P_{t-1})$.
ΔCOVAR	ΔCOVAR systemic risk measure of Adrian and Brunnermeier (2016).
MES	Marginal expected shortfall systemic risk measure of Acharya, Pedersen, Philippon, and Richardson (2017).
RESIDUAL_RISK	Residual risk obtained as the standard deviation of the residuals from a 2-factor model of bank stock returns on the market portfolio and interest rate factor (Goetz, Laeven, and Levine (2016)).
REPURCHASE_AGREEMENTS	Net repurchase agreements divided by total borrowings. Net repurchase agreements is measured as securities sold under agreements to repurchase minus securities purchased under agreements to resell. Total borrowings is measured as the sum of net repurchase agreements, commercial paper, brokered deposits, net federal funds, subordinated notes and debentures, and other borrowed money.
COMMERCIAL_PAPER	Commercial paper divided by total borrowings.
Control variables:	
BROKERED_DEPOSITS	Brokered deposits divided by total assets.
LARGE_TIME_DEPOSITS	Large time deposits (>$100,000) divided by total assets.
FOREIGN_DEPOSITS	Foreign deposits divided by total assets.
CORE_DEPOSITS	All deposits excluding brokered deposits, large time deposits, and foreign deposits divided by total assets.
SIZE	Natural logarithm of total assets [ln(assets)].
SIZE_SQUARED	Natural logarithm of total assets squared [$(\ln(\text{assets}))^2$].
EQUITY	Market value of equity divided by total assets.
NONPERFORMING_LOANS	Nonperforming loans divided by total assets.
PROFITABILITY	Net income divided by total assets.
NONINTEREST_INCOME	Noninterest income divided by interest income.
HEDGE	Sum of notional principal on foreign exchange futures and notional principal on interest rate swaps divided by total assets.
LIQUID_ASSETS	Sum of cash and Treasury securities divided by short-term borrowings.
COMMITMENTS	Sum of unused loan commitments and letters of credit divided by total assets.

has fewer than 59 daily return observations in a quarter, the standard deviation is set to missing (less than 1% of observations). This measure reflects the market's perception of the inherent risks in the banking structure, including risks that may arise from assets and liabilities (repos also exists on both the assets and liabilities sides). The primary focus is on capital market measures of risk, which have a different interpretation from financial statement measures, such as z-scores or loan loss provisions, which are interpreted as portfolio risk. Finally, Atkeson, Eisfeldt, and Weill (2017) show that the volatility of equity returns is a good measure for a firm's financial soundness and distance from insolvency.

ΔCOVAR: We also examine a systemic risk measure that captures a bank's tail risk. Krishnamurthy et al. (2014) note that the run in the repo market can contribute to the crisis through its effects on systemically large institutions. For example, they argue that while the contraction in repo is insignificant relative to the aggregate shadow banks' funding, the effects of repo are amplified if it disproportionally affected key institutions. To examine the contribution of repos to systemic risk, we consider ΔCOVAR (proposed by Adrian and Brunnermeier (2016)). We use quantile regressions to estimate ΔCOVAR at the worst 5% performance for a bank as being representative of the bank in distress. In other words, it is the difference between the financial system's value-at-risk conditional on bank i being in distress (at the 5% quantile) and the financial system's value-at-risk conditional on bank i being in its median state (at the 50% quantile). The Appendix provides the detailed construction for calculating ΔCOVAR.

MES: Acharya et al. (2017) suggest another measure of systemic risk called marginal expected shortfall, defined as the bank's stock returns when the market has the worst stock returns at the 5% level. Acharya et al. (2017) show that one can infer what happens to a bank's capital in a real crisis (what they call the systemic expected shortfall) from the performance of a firm during a "moderately bad day" for the market. Note that ΔCOVAR measures the externality a bank causes on the system, while MES focuses on how much a bank is exposed to a potential systemic crisis. The MES is a financial institution's losses in the tail of the aggregate industry's loss distribution. MES is measured during "normal" tail events and calculated as follows:

$$\text{MES}^i_{5\%} \quad \equiv \quad -E\left[\frac{W^i_1}{W^i_0} - 1 | I_{5\%}\right] \quad = \quad \frac{-1}{\#\text{days}} \sum_{t:\ \text{system is in its 5\% tail}} R^i_t,$$

where W^i is the market value of equity of firm i and $I_{5\%}$ is the 5% worst days in the market. Note that this measure is multiplied by -1 to obtain a measure consistent in interpretation with ΔCOVAR.

RESIDUAL_RISK: We consider a measure for the idiosyncratic risk component associated with bank risk. This measure of RESIDUAL_RISK is obtained from the following 2-factor model:

$$R_{it} \quad = \quad \beta_{0i} + \beta_{1i} R_{mt} + \beta_{2i} \text{Yield}_t + \varepsilon_{it}$$

where R_{it} is the daily return of firm i, including dividends, over the period ending at time t; R_{mt} is the daily return of the equally-weighted index of New York Stock Exchange/American Stock Exchange/Nasdaq stocks, including dividends, over the period ending at time t; Yield_t is the change in the yield on 3-month Treasury bills [(3-month rate_t) – (3-month rate_{t-1})]. Yield_t captures changes in short-term rates, and a positive value represents increases in short-term rates. This 2-factor model is estimated for each bank-quarter, and the standard deviation of the residuals is considered a measure of RESIDUAL_RISK. This measure has previously been used for bank risk in Flannery and James (1984a), Demsetz and Strahan (1997), and Goetz et al. (2016). We confirm that adding the default risk factor does not materially change the results.

2. Repurchase Agreements and Commercial Paper

For our independent variables, we begin with analyzing our main variables of interest, namely, REPURCHASE_AGREEMENTS and COMMERCIAL_PAPER.

REPURCHASE_AGREEMENTS: Our first short-term debt variable is net repos and is defined as securities sold under agreements to repurchase [BHCKB995] minus securities purchased under agreements to resell [BHCKB989]. Since our measure is the rollover frequency of short-term debt from repos, we construct our measure as net repos scaled by total borrowing. Total borrowing is measured as the sum of net repurchase agreements, commercial paper [BHCK2309], brokered deposits [BHDMA243], net federal funds purchased [BHDMB993 − BHDMB987], subordinated notes and debentures [BHCK4062], and other borrowed money [BHCK3190].

COMMERCIAL_PAPER: Our construction of commercial paper involves the total amount of commercial paper borrowed by the BHC on the liabilities side of the balance sheet within the category of "other borrowed money." The second short-term debt variable is the amount of commercial paper borrowed by the bank [BHCK2309] scaled by total borrowing, to obtain a measure consistent in interpretation with REPURCHASE_AGREEMENTS.

3. Control Variables

We include a large number of control variables that might be correlated with bank risk.

BROKERED_DEPOSITS: Our first control variable is the amount of brokered deposits borrowed by the bank. A few early studies focused on the role of brokered deposits in the late 1980s' thrift crisis. Goldberg and Hudgins (2002) found that failing thrifts were more active in using brokered deposits than solvent thrifts. Cook and Spellman (1991) found that brokered deposits significantly contributed to default risk. Regulatory measures from both the Financial Institutions Reform, Recovery, and Enforcement Act of 1989 and the Federal Deposit Insurance Corporation (FDIC) Improvement Act attempted to limit the acceptance of brokered deposits to allow thrifts to meet their capital adequacy guidelines. More recently, Cole and White (2011) find that higher levels of brokered deposits had a positive effect on bank failure in the crisis year of 2009. However, a study by the FDIC (2011) finds that brokered deposits do not increase the probability of a bank's failure. We examine total brokered deposits [BHDMA243 + BHDMA164] scaled by total assets.

LARGE_TIME_DEPOSITS: Cornett, McNutt, Strahan, and Tehranian (2011) show that banks that relied more heavily on wholesale sources of financing, such as large time deposits, had a reduced lending capacity during the crisis. Large wholesale deposits are also considered uninsured if they are above the insurance limit and are generally considered a relatively unstable source of financing because a significant decrease in a bank's fundamental value will incentivize these depositors to run. This variable is constructed as large time deposits over $100,000 [BHCB2604 + BHOD2604] scaled by total assets.

FOREIGN_DEPOSITS: Foreign deposits are considered to be less stable deposits and are recognized by the Basel Committee on Banking Supervision (BCBS). For example, in Basel III's liquidity coverage ratio (BCBS (2013), (2014), Du (2017)), foreign deposits are classified with a higher run-off rate (10%) than core deposits (3%). We measure this variable as total interest and noninterest bearing deposits in foreign offices [BHFN6631 + BHFN6636] scaled by total assets.

CORE_DEPOSITS: Banks that rely more on demand deposits might experience less risk than banks that rely more on other forms of short-term financing.[5] We proxy for this type of debt by including the ratio of deposits [BHDM6631 + BHDM6636] (excluding brokered deposits, large time deposits, and foreign deposits) to total assets.

[5]In fact, Flannery and James (1984b) document evidence that demand deposits have effective maturities that resemble those of a longer-term security.

SIZE: It seems reasonable that BHCs of different sizes have different risks. To control for this possibility, we proxy for bank size by the natural logarithm of bank assets [BHCK2170].

SIZE_SQUARED: To control for any nonmonotonicity in bank size, we also include the natural logarithm of total assets squared.

EQUITY: Banks that are more leveraged are more likely to experience a larger variation in equity values given a shock to their asset value. We proxy for leverage by the ratio of the market value of equity to assets. Note that our proxy is inversely related to leverage.

NONPERFORMING_LOANS: We construct a variable to capture the risks associated with lending. It is defined as the ratio of nonperforming loans [BHCK5525 + BHCK5526] to assets.

PROFITABILITY: We proxy for bank profitability by a bank's return-on-assets variable, defined as the ratio of net income [BHCK4340] to total assets. Return on assets is a better measure of profitability than return on equity because it is not distorted by high equity multipliers common in this industry. Higher profitability may signal a diversified funds source (resulting in a lower cost of capital) or a risky loan portfolio.

NONINTEREST_INCOME: Stiroh (2006) and Brunnermeier, Dong, and Palia (2016) document that BHCs shift more into alternative revenue sources captured by noninterest income. These activities include income from fiduciary activities, trading revenue, service charges, fees and commissions, underwriting, and advising services. Additionally, DeYoung and Rice (2004) and Stiroh (2004) find evidence of higher volatility for banks with greater noninterest income. Consistent with these studies, we define our proxy variable as the ratio of noninterest income to interest income [BHCK4079 / BHCK4107].

HEDGE*:* We use this variable to measure the degree of a bank's use of derivative instruments. It is defined as the ratio of the sum of notional principal on foreign exchange futures and notional principal on interest rate swaps [BHCK8694 + BHCK3450] to total assets. Similar to Demsetz and Strahan (1997), notional principal amounts are used to reflect the scale of derivative activity, although they are not representative of the marked-to-market values. This ratio controls for how hedged a bank is against interest rate and foreign exchange risks and is expected to have a positive coefficient.

LIQUID_ASSETS: Acharya and Skeie (2011) show that in addition to short-term leverage, the illiquidity of assets is associated with higher rollover risk. Morris and Shin (2016) illustrate a model that incorporates the interaction between insolvency risk and illiquidity risk as a function of total credit risk. Illiquidity risk is the probability of default due to a run when an institution would have otherwise been solvent. A major determinant of illiquidity risk is the liquidity ratio, defined as value of cash that can be realized in the short run relative to short-run liabilities. A shift to holding more liquid assets increases the liquidity ratio and, thus, reduces the likelihood that short-term creditors choose to not rollover funding at the interim date. Bolton, Chen, and Wang (2011) examine the role of cash reserve management as a tool for dynamic risk management. Holmstrom and Tirole (2000) identify Treasury bonds and cash as the two main buffers against shocks since they are instruments that a firm can quickly resell or pledge as collateral at their true value when an institution is strapped for cash. Thus, our measure of liquidity is the sum of cash [BHCK0081 + BHCK0395] and Treasury securities [BHCK1287] scaled by short-term debt (securities purchased under agreements to resell, commercial paper, and brokered deposits maturing in less than 1 year).

COMMITMENTS: Gatev, Schuermann, and Strahan (2009) show that deposits may help hedge liquidity risk arising from off-balance sheet arrangements such as loan commitments. Banks may be exposed to liquidity risks when they have excessive loan commitments, especially during economic downturns when borrowers collectively draw down en masse. This variable is the sum of unused commitments [BHCK3814 + BHCK3816 + BHCK3817 + BHCK6550], financial standby letters of credit [BHCK6566 + BHCK3820], performance standby letters of credit [BHCK6570 + BHCK3822], and commercial letters of credit [BHCK3411] scaled by total assets.

C. Summary Statistics

Table 2 reports the summary statistics for the sample of approximately 6,000 BHC-quarter observations from 2002 to 2009. On average, STANDARD_DEVIATION is 19.02, ΔCOVAR is 0.78, MES is 1.82, and RESIDUAL_RISK is 4.01. We find that net repurchase agreements are 27% of total borrowings, while commercial paper accounts for an extremely small proportion of total borrowings (1%). On average, brokered, large time, foreign, and core deposits account for 6%, 12%, 1%, and 59% of total assets, respectively. The mean asset size (measured as the natural logarithm of total assets) is larger than the median, suggesting that the distribution of banks is right-skewed. The average asset size is $3.3 billion, nonperforming loans account for less than 1% of total assets, return on assets is a little under 1%, and the average ratio of equity to assets is 16%, suggesting that banks have high financial leverage. The notional principal on derivative contracts (interest rate swaps and foreign exchange futures) accounts for 15% of total assets,

TABLE 2
Summary Statistics

Table 2 reports the summary statistics for the sample of 216 U.S. banks from 2002 to 2009. Variable definitions are provided in Table 1. All variables are winsorized using median plus or minus five times the interquartile range.

Variable	No. of Obs.	Mean	Median	Std. Dev.
STANDARD_DEVIATION	6,814	19.02	14.63	13.45
ΔCOVAR	6,786	0.78	0.66	0.67
MES	6,810	1.82	1.34	2.57
RESIDUAL_RISK	6,815	4.01	1.56	9.76
REPURCHASE_AGREEMENTS	6,891	0.27	0.17	0.46
COMMERCIAL_PAPER	6,891	0.01	0.00	0.03
BROKERED_DEPOSITS	6,891	0.06	0.00	0.13
LARGE_TIME_DEPOSITS	6,896	0.12	0.11	0.07
FOREIGN_DEPOSITS	6,887	0.01	0.00	0.03
CORE_DEPOSITS	6,894	0.59	0.61	0.13
SIZE	6,912	14.78	14.39	1.58
SIZE_SQUARED	6,912	220.88	207.18	51.01
EQUITY	6,810	0.16	0.15	0.07
NONPERFORMING_LOANS	6,912	0.01	0.01	0.01
PROFITABILITY	6,912	0.01	0.01	0.01
NONINTEREST_INCOME	6,912	0.27	0.20	0.27
HEDGE	6,887	0.15	0.00	0.99
LIQUID_ASSETS	5,803	0.83	0.84	1.42
COMMITMENTS	6,896	0.09	0.08	0.05

liquid assets (cash and Treasuries) account for only 83% of short-term debt, and loan commitments average 9% of total assets.

In Table 3, we provide the Pearson correlation coefficients for all our variables. We find that PROFITABILITY and EQUITY have the highest correlation coefficient of 0.59, followed by a correlation coefficient of 0.55 between SIZE_SQUARED and FOREIGN_DEPOSITS. However, when we compute the condition index of Belsley, Kuh, and Welsch (1980), we find that it is lower than 10, suggesting no evidence of multicollinearity in our regression specification. In order to further ensure the robustness of our results, we drop the variables PROFITABILITY and SIZE_SQUARED and find no significant change in our results.

IV. Tests and Results

We begin by examining the impact of short-term debt and liquidity measures on bank risk in the pre-crisis period of 2002Q1–2007Q2. In this regression, we estimate a BHC-level fixed-effects model to control for time-invariant factors such as bank culture and market power. We also include quarterly dummy variables in order to capture any macroeconomic and financial factors that are common to all BHCs in the sample. In Table 4, we present the results of such a regression and do not report the bank effects or the quarterly dummies. Petersen (2009) notes that in addition to time-series dependence, where residuals of a firm may be correlated across time, there may also be the presence of a time effect, where the residuals of a given year may be correlated across different firms. To resolve this issue, we cluster the standard errors by both firm and time.

In column 1 of Table 4, we examine the impact of REPURCHASE_AGREEMENTS on total bank risk while including the various control variables. We find that increasing repos increases bank risk at the 5% level of statistical significance. A 1-standard-deviation increase in repos increases bank risk by 35 basis points. This result suggests that higher levels of repo financing are associated with higher bank risk. The remainder of the control variables show that foreign deposits and nonperforming loans are associated with greater risk. The proportion of equity to assets and PROFITABILITY is negatively related to risk. SIZE is positively related to risk, but the relationship is nonmonotonic. Brokered deposits, core deposits, noninterest income, derivatives hedging, liquid assets, and loan commitments are not found to be significantly related to bank risk.

In column 2 of Table 4, we examine the impact of commercial paper on bank risk while including the various control variables. We find that COMMERCIAL_PAPER is not statistically significantly related to bank risk. The results on the control variables that we find in column 1 are generally consistent in this specification. In column 3, we include repos and commercial paper together. We find that repos continue to be negatively and statistically significantly related to bank risk, whereas commercial paper continues to be statistically insignificantly related to bank risk. The results on the control variables do not generally change. The result that holding additional liquid assets does not reduce bank risk may be surprising and counterintuitive to the notion that they provide a buffer against liquidity shocks to a bank. However, this result is consistent with the arguments of

TABLE 3

Correlation Matrix

Table 3 reports the Pearson correlations for all variables. All variables are winsorized using median plus or minus five times the interquartile range. Variable definitions are provided in Table 1.

Variable	Std. Dev.	Repos	Comm. Paper	Brok. Dep.	Large Time	Foreign	Core	Size	Size Sq.	Equity	Nonper Loans	Profit	Nonint. Income	Hedge	Liquid Assets	Commitments
STANDARD_DEVIATION	1.00															
REPURCHASE_AGREEMENTS	−0.08	1.00														
COMMERCIAL_PAPER	−0.04	−0.12	1.00													
BROKERED_DEPOSITS	0.38	−0.10	−0.08	1.00												
LARGE_TIME_DEPOSITS	0.10	0.02	−0.14	0.23	1.00											
FOREIGN_DEPOSITS	−0.02	−0.07	0.37	−0.06	−0.19	1.00										
CORE_DEPOSITS	−0.11	0.10	−0.32	−0.12	−0.21	−0.47	1.00									
SIZE	0.01	−0.07	0.36	−0.11	−0.26	0.52	−0.43	1.00								
SIZE_SQUARED	0.00	−0.08	0.38	−0.11	−0.27	0.55	−0.45	1.00	1.00							
EQUITY	−0.50	0.09	0.09	−0.31	−0.16	0.03	0.11	0.08	0.07	1.00						
NONPERFORMING_LOANS	0.56	−0.08	0.00	0.34	0.09	0.02	−0.11	0.08	0.09	−0.49	1.00					
PROFITABILITY	−0.44	0.05	0.06	−0.30	−0.14	0.02	0.02	0.05	0.05	0.59	−0.50	1.00				
NONINTEREST_INCOME	−0.07	0.00	0.35	−0.16	−0.31	0.43	−0.40	0.49	0.50	0.21	−0.04	0.18	1.00			
HEDGE	0.00	−0.09	0.41	−0.04	−0.16	0.50	−0.33	0.50	0.55	−0.08	0.10	0.00	0.16	1.00		
LIQUID_ASSETS	−0.13	−0.07	0.03	−0.07	0.07	0.07	0.05	0.29	0.29	0.14	−0.15	0.10	0.02	0.10	1.00	
COMMITMENTS	−0.05	−0.12	−0.05	−0.10	0.00	−0.03	0.08	−0.04	−0.04	0.08	−0.03	0.06	0.02	−0.03	0.08	1.00

TABLE 4
Fixed-Effects Regressions of Bank Risk in the Pre-Crisis Period

Table 4 reports the results of fixed-effects regressions of bank risk (proxied by the standard deviation of stock returns) on a number of independent variables in the pre-crisis period 2002Q1–2007Q2. Quarter- and bank-level fixed effects are estimated but not reported. All variables are winsorized using median plus or minus five times the interquartile range. Robust standard errors are corrected for clustering across both year and firm (Petersen (2009)). Variable definitions are provided in Table 1. *t*-statistics are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Variable	1	2	3
REPURCHASE_AGREEMENTS	0.762**		0.834**
	(2.01)		(2.01)
COMMERCIAL_PAPER		5.846	5.932
		(0.86)	(0.78)
BROKERED_DEPOSITS	−2.26	−2.45	−2.59
	(−0.85)	(−0.94)	(−0.95)
LARGE_TIME_DEPOSITS	4.86	5.26*	5.31*
	(1.64)	(1.78)	(1.79)
FOREIGN_DEPOSITS	7.62*	7.935*	7.772*
	(1.69)	(1.71)	(1.72)
CORE_DEPOSITS	0.858	1.26	0.781
	(0.64)	(0.73)	(0.47)
SIZE	0.948***	0.957***	0.875***
	(2.72)	(3.00)	(2.78)
SIZE_SQUARED	−0.105***	−0.099***	−0.085**
	(−2.97)	(−2.85)	(−2.39)
EQUITY	−5.27*	−5.55*	−4.59
	(−1.83)	(−1.75)	(−1.45)
NONPERFORMING_LOANS	90.59***	93.23***	91.59***
	(2.91)	(2.96)	(2.94)
PROFITABILITY	−83.0**	−82.7**	−81.6**
	(−2.15)	(−2.16)	(−2.11)
NONINTEREST_INCOME	−1.05	−0.936	0.845
	(−1.23)	(−1.37)	(−1.50)
HEDGE	−0.522	−0.075	−0.435
	(−0.72)	(−0.16)	(−0.52)
LIQUID_ASSETS	−0.143	−0.153	−0.159
	(−0.75)	(−0.81)	(−0.94)
COMMITMENTS	−3.26	−3.45*	−3.39
	(−1.46)	(−1.63)	(−1.29)
No. of obs.	3,706	3,706	3,706
Adj. R^2	0.434	0.414	0.440

Diamond and He (2014) who argue that extra cash will not resolve the short-term debt-overhang problem because managers have an incentive to divert the cash rather than to hold it until a later period.

In summary, we find that bank risk is higher when the fraction of debt (excluding deposits) in repos is higher in the pre-crisis period. No significant relationship is found for commercial paper. These results are robust to including bank-level fixed effects to control for unobservable factors, quarterly dummy variables, standard errors corrected for clustering across firm, and time. The importance of repos to increasing bank risk in the pre-crisis period is consistent with the argument of Gorton and Metrick (2012a), (2012b) who find a significant run in the repo market.

In Table 5, we turn our attention to the crisis period, by expanding our sample period through 2008 in column 1 and through 2009 in column 2. Consistent with FPZ (2012), we use two definitions of the crisis period. The first is defined as the period 2007Q3–2008Q4. This is the period on which FPZ focuses their

TABLE 5

Fixed-Effects Regressions of Bank Risk in the Pre-Crisis and Crisis Periods

Table 5 reports the results of fixed-effects regressions of bank risk (proxied by the standard deviation of stock returns) on a number of independent variables in the pre-crisis and crisis periods. Column 1 reports the results for the crisis period defined as 2007Q3–2008Q4. Column 2 reports the results for the crisis period defined as 2007Q3–2009Q4. Quarter- and bank-level fixed effects and control variables are estimated but not reported. All variables are winsorized using median plus or minus five times the interquartile range. Robust standard errors are corrected for clustering across both year and firm (Petersen (2009)). Variable definitions are provided in Table 1. *t*-statistics are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Variable	1	2
Crisis dummy (2007Q3–2008Q4)	15.94***	
	(14.29)	
Crisis dummy (2007Q3–2009Q4)		7.51***
		(6.18)
REPURCHASE_AGREEMENTS	0.752*	0.814**
	(1.88)	(2.24)
COMMERCIAL_PAPER	4.95	3.37
	(0.55)	(0.53)
REPURCHASE_AGREEMENTS × CRISIS	−4.54***	−4.48***
	(−3.42)	(−3.32)
COMMERCIAL_PAPER × CRISIS	−14.60	−14.93
	(−1.30)	(−1.04)
No. of obs.	4,878	5,685
Adj. R^2	0.665	0.652

analysis because of the substantial uncertainty caused by the possibility of bank nationalization in 2009. The second definition of the crisis includes 2009 and is, therefore, defined as 2007Q3–2009Q4. We calculate the interaction of the crisis periods with both repos and commercial paper and reestimate the regressions of column 4 of Table 4. We present these results in Table 5 while not reporting the regression coefficients and the *t*-statistics on the control variables (for brevity).

As expected, we find that a bank's volatility is higher in the crisis period when compared to the pre-crisis period. Consistent with the results of Table 4, we find that repos increased bank risk in the pre-crisis period, and this relationship is statistically insignificant for commercial paper. The interaction term between REPURCHASE_AGREEMENTS and the crisis dummy is negative and significant at the 1% level, suggesting the impact of repos on bank risk is sensitive to the subperiod definitions. When we examine the impact of the crisis, we find that increasing repos *decreased* bank risk. Consistent with the results for the pre-crisis period, we find that commercial paper is statistically insignificantly related to bank risk in the crisis.

The results in this table merit further discussion. It is clear that the relationship between repos and risk is cyclical; they are positively related in the pre-crisis period and negatively related in the crisis period. A natural question to ask is whether repo funding is perceived by capital markets to be a riskier activity or whether there is a reverse-causality explanation. In other words, the results may imply that riskier banks may need to rely on repo financing (because they are unable to obtain funding from other sources) or that they are driven by some other omitted variable. Additionally, in the crisis period, riskier banks may be unable to access repo markets, further confounding the relationship between repos and bank risk. We explore these possibilities later in the paper.

In Table 6, we use three alternative measures of bank risk, namely, ΔCOVAR (Adrian and Brunnermeier (2016)), MES (Acharya et al. (2017)), and RESIDUAL_RISK (Goetz et al. (2016)). During the crisis, we find that increases in repos decreased bank risk for all three risk measures. In the pre-crisis, RESIDUAL_RISK is positively correlated to bank risk, whereas the two measures that focus on extreme tail risk (ΔCOVAR and MES) were insignificantly correlated to bank risk. These results are generally similar to those found in Table 5.

In Panel A of Table 7, we examine if the change in repo funding from the pre-crisis to the crisis period is correlated to bank stock returns during the crisis. FPZ (2012) examine a cross-sectional regression of buy-and-hold returns during the crisis on bank performance during the crisis of 1998, along with other control variables measured in 2006. They find a positive relation between bank performance in 1998 and the returns in the crisis, which they attribute to persistence in a bank's risk culture. We use their control variables and regression specification and additionally include banks' change in repos from the pre-crisis to the crisis period. We find a positive relationship between the change in repo funding from the pre-crisis to the crisis period and stock returns in the crisis, while controlling for their 1998 performance variable. The positive coefficient on the change in REPURCHASE_AGREEMENTS is preliminary evidence that good banks that were able to increase their repo funding earned higher stock returns in the crisis.

In Panel B of Table 7, we examine what happened to bank performance from the pre-crisis to the crisis period when compared to the change in repo funding during the same periods. In column 1, we examine the relationship between the level of repos on the change in Tobin's Q from the pre-crisis to the crisis period. We find the relative level of repos during the crisis is associated with increases in Tobin's Q. In column 2, we find that an increase in the level of repos is

TABLE 6

Robustness Tests: Using Alternative Bank Risk Measures

Table 6 reports the results of fixed-effects regressions of alternative bank risk measures on a number of independent variables in the pre-crisis and crisis periods. Column 1 examines the ΔCOVAR systemic risk measure of Adrian and Brunnermeier (2016), column 2 examines the marginal expected shortfall (MES) systemic risk measure of Acharya et al. (2017), column 3 reports the results of RESIDUAL_RISK measured as the standard deviation of residuals from a 2-factor market model (Goetz et al. (2016)). Quarter- and bank-level fixed effects and control variables are estimated but not reported. All variables are winsorized using median plus or minus five times the interquartile range. Robust standard errors are corrected for clustering across both year and firm (Petersen (2009)). Variable definitions are provided in Table 1. *t*-statistics are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Variable	ΔCOVAR 1	MES 2	RESIDUAL_ RISK 3
Crisis dummy (2007Q3–2008Q4)	2.99*** (16.45)	2.172** (12.43)	0.043*** (7.59)
REPURCHASE_AGREEMENTS	0.039 (0.46)	0.002 (0.04)	0.001* (1.66)
COMMERCIAL_PAPER	2.149 (1.53)	−1.612 (−0.59)	0.007 (0.47)
REPURCHASE_AGREEMENTS × CRISIS	−0.753*** (−2.61)	−0.581** (−2.35)	−0.025** (−3.06)
COMMERCIAL_PAPER × CRISIS	0.126 (0.05)	3.532 (0.98)	−0.088 (−1.32)
No. of obs.	4,864	4,878	4,879
Adj. R^2	0.432	0.313	0.541

TABLE 7

Repurchase Agreements and Firm Value in the Crisis

Panel A of Table 7 reports the cross-sectional regressions of buy-and-hold returns during the financial crisis (2007Q3–2008Q4) on stock returns in 1998 (Fahlenbrach, Prilmeier, and Stulz (FPZ) (2012)), firm characteristics at year-end 2006, and the change in the mean level of repurchase agreements from the pre-crisis to the crisis period, ΔREPURCHASE_AGREEMENTS. As in FPZ, the control variables are the book-to-market ratio, the ratio of leverage to assets, and the natural logarithm of assets. Panel B reports the cross-sectional regressions of the change in Tobin's Q on REPURCHASE_AGREEMENTS at year-end 2006 or the change in the mean level of repurchase agreements from the pre-crisis to the crisis period. All variables are winsorized using median plus or minus five times the interquartile range. t-statistics are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Buy-and-Hold Returns	1	2
Stock returns in 2006	−0.072 (−0.39)	−0.067 (−0.36)
Book-to-market ratio at year-end 2006	−0.584** (−2.42)	−0.585** (−2.39)
Leverage at year-end 2006	0.012 (0.70)	0.013 (0.74)
Size at year-end 2006	0.01 (0.61)	0.008 (0.51)
Stock returns in 1998 (FPZ variable)	0.385 (1.54)	
Worst quartile of FPZ variable		−0.094 (−1.24)
2nd worst quartile of FPZ variable		−0.09 (−1.20)
3rd worst quartile of FPZ variable		−0.063 (−0.84)
ΔREPURCHASE_AGREEMENTS	0.033** (2.03)	0.034** (2.05)
No. of obs.	173	173
Adjusted R^2	0.060	0.046
Panel B. Change in Tobin's Q		
REPURCHASE_AGREEMENTS	0.009*** (4.28)	
ΔREPURCHASE_AGREEMENTS		0.006* (1.66)
No. of obs.	216	216
Adj. R^2	0.074	0.008

associated with increases in Tobin's Q. It may be argued that the specification in column 2 is a more robust specification to examine how repo financing is associated with returns; however, it is only statistically significant at the 10% level of significance. Consistent with the previous results, we find that the change in repo funding from the pre-crisis to the crisis period is positively related to changes in bank performance during the same periods.

We further investigate what happened to repo funding in the crisis using different tests. Specifically, we investigate why there is a differential effect of repos on bank risk when we compare the pre-crisis period to the crisis period. First, we split our sample of banks by quality into "good" banks and "bad" banks in the 6 quarters prior to the crisis (2006Q1–2007Q2). We proxy for bank quality by Tobin's Q (defined as the sum of market value of equity and book value of liabilities divided by assets) or ROA (defined as the ratio of net income to assets). Good quality banks are in the fourth quartile of either Tobin's Q or ROA, and bad quality banks are in the first quartile. Second, we examine the change in the mean repo funding between the pre-crisis and the crisis period for these two subsamples of banks. Panel A of Table 8 presents the results. For both definitions of bank quality (Tobin's Q and ROA), we find a statistically significant decrease in mean repo funding in the crisis when compared to the pre-crisis period for bad quality banks. No such result is found for good quality banks. These results help explain the negative relationship between repo funding and bank risk in the crisis, as good banks were able to continue funding their repos, whereas bad banks had to significantly decrease their repo funding.

In Panel B, we further explore the repo–risk relationship for banks characterized as either good or bad in the pre-crisis. Over the entire pre-crisis period from 2002Q1 to 2007Q2, Tobin's Q or ROA is averaged for each bank in the sample and, subsequently, sorted into quartiles. Firms in the top (bottom) quartile of Tobin's Q or ROA are considered good (bad) banks. Columns 1 and 2 examine the good and bad banks by Tobin's Q, and columns 3 and 4 examine good and bad banks by ROA. The results provide additional support to those found in Panel A. We find that banks associated with low Tobin's Q or ROA have a positive repo–risk relationship in the pre-crisis. In columns 2 and 4, the coefficient on REPURCHASE_AGREEMENTS is significant and positive. On the other hand, the coefficient on REPURCHASE × CRISIS is negative for good banks, while it is insignificantly different from zero for bad banks during the crisis. This result is consistent with the interpretation that good quality banks were able to continue funding in the repo market during the crisis, while bad quality banks generally

TABLE 8

Bank Quality and Repurchase Agreements

Panel A of Table 8 provides univariate analysis of the relationship between bank quality and average repo levels. The pre-crisis period is defined as the 6 quarters from 2006Q1 to 2007Q2, and the crisis period is defined as the 6 quarters from 2007Q3 to 2008Q4. Bank quality is measured using Tobin's Q (defined as the sum of market value of equity and book value of liabilities divided by assets) or ROA (defined as the ratio of net income to assets) in the pre-crisis period. Mean repos is defined as the total net repurchase agreements divided by the average borrowings in the crisis period. Panel B reports the bank-level fixed-effects regressions of bank risk by average Tobin's Q or average ROA during the pre-crisis period (from 2002Q1–2007Q2). Banks are sorted into quartiles; firms in the top (bottom) quartile of Tobin's Q or ROA are considered good (bad) banks. Quarter- and bank-level fixed effects and control variables are estimated but not reported. All variables are winsorized using median plus or minus five times the interquartile range. Robust standard errors are corrected for clustering across both year and firm (Petersen (2009)). Variable definitions are provided in Table 1. t-statistics are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Mean Repurchase Agreements across Good and Bad Quality Banks (bank quality proxied by Tobin's Q or ROA)

	Pre-Crisis	Crisis	Difference
	1	2	3
Tobin's Q quartile 1 (low)	1.469	1.031	(−1.79)*
Tobin's Q quartile 4 (high)	1.719	1.731	(0.03)
ROA quartile 1 (low)	1.594	0.942	(−2.23)**
ROA quartile 4 (high)	1.454	1.830	(1.10)

Panel B. Pre-Crisis Regressions by Tobin's Q and ROA

	Risk Tobin's Q (good)	Risk Tobin's Q (bad)	Risk ROA (good)	Risk ROA (bad)
Variables	1	2	3	4
REPURCHASE_AGREEMENTS	0.01	0.82*	0.36	1.21**
	(0.04)	(1.92)	(0.54)	(2.11)
REPURCHASE × CRISIS	−4.30***	−1.78	−2.62*	−0.63
	(−3.33)	(−1.07)	(−1.89)	(−0.53)
No. of obs.	1,324	1,167	1,307	1,205
Adj. R^2	0.659	0.567	0.660	0.569

decreased their repo funding during the crisis. Thus, the repo–risk relationship for bad banks is insignificant during the crisis.

V. Conclusions

This paper is motivated by the financial crisis of 2007 as well as the number of recent models of rollover risk that arises from banks using short-term debt. Using a large sample of U.S. BHCs for the period 2002–2009, we find that increases in repurchase agreements were recognized by external capital markets to increase bank risk in the pre-crisis period 2002Q1–2007Q2. No such effect is found for commercial paper. The importance of repos to increasing bank risk is consistent with the argument of Gorton and Metrick (2012a), (2012b) who find a significant run in the repo market. In the crisis, we find a negative relationship between repos and bank risk. This result is attributed to good banks being able to continue funding their repos, whereas bad banks had to significantly decrease their repo funding. We also find that banks were unable to reduce their risk either in the pre-crisis or the crisis period by using their available liquidity. Finally, we find that good banks that were able to get repo funding during the crisis had better performance. Given that we only examine commercial banks and the crisis hit noncommercial investment banks, such as Lehman and Bear Stearns, more severely, any result that we find is a lower bound on repo funding and bank risk.

To the extent that we primarily use data from call reports (FR Y-9C), we are unable to obtain the type of collateral backing the repos held by the bank (i.e., whether the collateral is Treasury bonds, agency, or MBS). Future research might examine this role of collateral and whether corporate governance mechanisms, such as managerial incentive pay, worked in conjunction with repo funding to increase risk.

Appendix. Construction of ΔCOVAR

This Appendix describes the calculation of the ΔCOVAR measure of systemic risk, proposed by Adrian and Brunnermeier (2016). To estimate an individual bank's systemic risk contribution, the first step is to estimate the following:

$$\text{(A-1)} \qquad X_t^i = \alpha^i + \gamma^i Z_{t-1} + \varepsilon_t^i,$$

where X_t^i = the weekly growth rate of the market-valued assets of bank i, calculated as $(\text{MA}_t - \text{MA}_{t-1})/\text{MA}_t$. The market-to-book ratio is applied to book assets to obtain a measure of market-valued assets: MA_t = (market value equity/book value equity)$_t$ × (book value assets)$_t$. Z_{t-1} is a vector of lagged state variables that are known to capture time variation in conditional moments of returns and are highly liquid. These include market volatility, market return, change in short-term Treasury bill (T-bill) rates, change in the slope of the yield curve, and the default risk premium. The VIX index is included to capture implied market volatility, and data are reported from the Chicago Board Options Exchange. Weekly market returns are the value-weighted equity market returns from CRSP. The change in short-term T-bill rates is the change in the yield on a 3-month T-bill estimated as follows: (3-month rate$_t$) – (3-month rate$_{t-1}$). The change in the slope of the yield curve is the change in the spread between 10-year and 3-month Treasury rates, estimated as (10-year rate – 3-month rate)$_t$ – (10-year rate – 3-month rate)$_{t-1}$. The default risk premium is the change in the spread between rates on Moody's Baa-rated corporate bonds and those on 10-year Treasury notes, estimated as follows: (Baa rate – 10-year rate)$_t$ – (Baa rate – 10-year rate)$_{t-1}$.

Equation (A-1) is run using quantile regressions at the median (50%) and 5% to obtain the value at risk from the estimated coefficients:

$$\text{(A-2)} \qquad \text{VAR}_t^i(q) = \hat{\alpha}^i + \hat{\gamma}^i Z_{t-1}.$$

The next step is to obtain the financial system's value at risk (VAR) conditional on bank *i* being in distress and the financial system's value at risk conditional on bank *i* being in its median state. The following quantile regression at 5% is estimated:

$$\text{(A-3)} \qquad X_t^{\text{system}} = \alpha^{\text{system}|i} + \beta^{\text{system}|i} X_t^i + \gamma^{\text{system}|i} Z_{t-1} + \varepsilon^{\text{system}|i}$$

where X_t^{system} is the weekly growth rate of the total value-weighted market assets of all banks in the sample at time t. The estimated values from equation (A-3) along with the $\text{VAR}_t^i(q)$ obtained from equation (A-2) yield the systemic risk when bank i's return is in the 5% quantile and when it is in the median. It is calculated as follows:

$$\text{(A-4)} \qquad \text{COVAR}_t^i(50\%) = \hat{\alpha}^{\text{system}|i} + \hat{\beta}^{\text{system}|i}\text{VAR}_t^i(50\%) + \hat{\gamma}^{\text{system}|i} Z_{t-1},$$

$$\text{(A-5)} \qquad \text{COVAR}_t^i(5\%) = \hat{\alpha}^{\text{system}|i} + \hat{\beta}^{\text{system}|i}\text{VAR}_t^i(5\%) + \hat{\gamma}^{\text{system}|i} Z_{t-1}.$$

The final measure is computed as the difference between the financial system's value at risk conditional on bank *i* being in distress (at the 1% quantile) and the financial system's value at risk conditional on bank *i* being in its median state (at the 50% quantile):

$$\text{(A-6)} \qquad \Delta\text{COVAR}_t^i = \text{COVAR}_t^i(1\%) - \text{COVAR}_t^i(50\%) = \hat{\beta}^{\text{system}|i}(\text{VAR}_t^i(5\%) - \text{VAR}_t^i(50\%)).$$

ΔCOVAR_t^i is computed for each firm-week from equation (A-6) and aggregated to obtain a quarterly measure (ΔCOVAR).

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