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What is the systemic risk exposure of financial institutions?

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ABSTRACT

I compare the performance of three measures of institution-level systemic risk exposure — Exposure CoVaR (Adrian and Brunnermeier, 2016), systemic expected shortfall (Acharya et al., 2016), and Granger causality (Billio et al., 2012). I modify Exposure CoVaR to allow for forecasting, and estimate the ability of each measure to forecast the performance of financial institutions during systemic crisis periods in 1998 (LTCM) and 2008 (Lehman Brothers). I find that Exposure CoVaR forecasts the within-crisis performance of financial institutions, and provides useful forecasts of future systemic risk exposures. Systemic expected shortfall and Granger causality do not forecast the performance of financial institutions reliably during crises. I also find, using cross-sectional regressions, that foreign equity exposure and securitization income determine systemic risk exposure during the 1998 and 2008 crises, respectively; financial institution size determines systemic risk exposure during both crisis periods; and executive compensation does not determine systemic risk exposure.

1. Introduction

Events beginning in September 2008, including the collapse of Lehman Brothers and the rescue of AIG, showed the effects that a systemic crisis can have on the economy.[2] The distress and even failure of some key institutions during that time prevented the financial system from functioning normally and led to further distress of financial institutions. Because regulators, investors, and executives had a limited understanding of the exposure of individual institutions to systemic risk, it was difficult for them to effectively manage institutions during the crisis. Thus, going forward, it is important to have an effective measure of the systemic risk exposure of financial institutions. A systemic risk exposure measure is a forecast of the performance of a financial institution conditional on a crisis. Therefore, such a measure makes it possible to assess which institutions will be seriously endangered if a crisis were to occur. Further, a knowledge of which institutions have higher systemic risk exposures relative to their peers will enable researchers and regulators to investigate what factors determine each institution's level of systemic risk exposure.

This paper investigates the systemic risk exposure of U.S. financial institutions. I evaluate the ability of existing measures of systemic risk exposure to forecast the within-crisis performance of financial institutions. I consider two crisis periods: the LTCM crisis of 1998 and the Lehman Brothers crisis of 2008 (following Fahlenbrach et al., 2012). Because each measure was developed to explain the 2008 crisis, estimates using data from the 1998 crisis can serve as out-of-sample tests of each measure's forecasting ability. I show that a modified version of the CoVaR measure based on Adrian and Brunnermeier (2016) is more effective in forecasting systemic risk exposure compared to other methods. I then study the determinants of a financial institution's systemic risk exposure. I find that in 1998 exposure to foreign equities determines an institution's systemic risk exposure; while in 2008 securitization activity determines an institution's systemic risk exposure. I also find that institution size is an important factor, but variables which proxy for interconnectedness in the financial system (i.e. derivatives or inter-bank loans) may not play a role.

The three measures of institution-level systemic risk exposure I investigate are Exposure CoVaR (Adrian and Brunnermeier, 2016),

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[2] Acharya (2009) defines a financial crisis as systemic if "many banks fail together, or if one bank's failure propagates as a contagion causing the failure of many banks."

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1572-3089/

systemic expected shortfall (SES, Acharya et al., 2016), and Granger causality (Billio et al., 2012).[3] Exposure CoVaR uses quantile regressions to estimate the sensitivity of the value-at-risk (VaR) of an institution's assets to fluctuations in the VaR of the total assets of the financial system. VaR is defined as the loss that will not be exceeded at some specified confidence level (Hull, 2009). SES uses an expected shortfall methodology to estimate the sensitivity of an institution's stock returns to overall stock market returns. Expected shortfall (ES) is defined as the expected loss an institution faces conditional on being in the tail of its distribution of returns (Hull, 2009). Granger causality quantifies the number of other institutions which cause the returns of a single institution. The Granger causality measure thus provides an estimate of the number of other financial institutions to which a single financial institution is connected. All three measures directly estimate the systemic risk exposure of a given financial institution. In contrast to systemic risk exposure measures which show how a crisis affects a financial institution, systemic risk contribution measures estimate the sensitivity of the financial system to a tail event in a single institution. This paper focuses solely on exposure to systemic risk.

The CoVaR model in Adrian and Brunnermeier (2016) is estimated unconditionally using all the available data dating back to 1986. This is in contrast to the other measures, which use only a portion of the data available at a given time. I therefore modify the CoVaR model of Adrian and Brunnermeier (2016) so that the measure at any point in time is estimated using only a limited portion of past data. Through most of the paper, I focus on estimations of CoVaR where I use two year rolling windows of past data but I also discuss alternative implementations. My modification makes it possible for an institution's systemic risk exposure to evolve over time. I call the modified measure "Adapted Exposure CoVaR" when it is estimated using these two-year rolling windows. Moreover, the Exposure CoVaR methodology examines the change in the risk exposure of an institution given that a systemic crisis occurs. Thus, it is not clear that a measure such as this will forecast the performance of a financial institution on an out-of-sample basis. Therefore, to estimate systemic risk exposure throughout the paper, I focus on a coefficient used within the CoVaR methodology. This coefficient, Adapted Exposure CoVaR beta, estimates the sensitivity of the market value of assets of an institution to changes in the market value of the assets of the entire financial system.

I show that, among these measures, the CoVaR methodology of Adrian and Brunnermeier (2016) is the measure which best forecasts the within-crisis performance of financial institutions over multiple crisis periods. Using a sample of the 25 largest banks, insurers, and brokers in the U.S., I demonstrate that a one-standard deviation increase in systemic risk exposure led to decreases of 0.82% and 1.60% in the market value of the assets of a given financial institution during the worst one-week periods of the LTCM and Lehman Brothers crises, respectively. This represents a decrease of 29.08% and 36.36% below the mean asset returns during each week. Neither SES nor Granger causality forecast the performance of financial institutions reliably during the worst weeks of these systemic crises.

I also examine the time-series properties of the measures of systemic risk exposure by estimating the ability of each measure to forecast future risk exposures. Such predictive power would help ensure that at the onset of a crisis, the set of "systemically important" institutions is not different from the group designated as such prior to the crisis. I find that Adapted Exposure CoVaR beta is more effective than other measures along this criterion. My regressions show that pre-crisis exposure in terms of Adapted Exposure CoVaR beta is positively related to within-crisis exposure levels, implying that institutions that are systemically risky prior to a crisis remain risky during the crisis. I do not find similar forecasting power for the SES or Granger causality measures.

I further find that estimating systemic risk exposures using different time-series of available data leads to different levels of estimated exposure for the same institution. Specifically, measures calculated using the entire set of available data prior to a crisis are not successful in forecasting the within-crisis performance of financial institutions. In contrast, measures calculated using data available in the two-year window before a crisis begins are successful in forecasting the within-crisis performance of financial institutions. This shows that systemic risk exposure changes dynamically over time within institutions, and that the modification to Exposure CoVaR that I propose is essential if it is to be useful as a forecasting tool.

This paper also examines how the systemic risk exposure measures perform in terms of forecasting stock returns during a crisis period. The market value of assets is an important measure, as it addresses the concern of institution solvency during crisis periods. However, stock returns are also integral to the viability of institutions, and they are used to calculate both SES and Granger causality. I find that SES forecasts stock returns during the Lehman Brothers crisis period, but does not forecast stock returns during the LTCM crisis period. Adapted Exposure CoVaR and Granger causality fail to forecast stock returns during both periods. Because these variables fail the out-of-sample forecasting test, they should not be used as forecasting tools in terms of stock returns.

I also examine the determinants of Adapted Exposure CoVaR beta. In cross-sectional regressions, I show that in the 1998 and 2008 crises, financial institutions with higher exposure to foreign equity and higher levels of securitization income, respectively, have larger Adapted Exposure CoVaR betas. In both crisis periods, larger financial institutions have greater Adapted Exposure CoVaR betas. I find that one-standard deviation increases in firm size are associated with an increase of 38.76–56.33% in Adapted Exposure CoVaR beta, while increases in foreign equity exposure and securitization income are related to increases of 10.85% and 8.86%, respectively. I also find that loans to other domestic financial institutions, derivatives positions, and executive compensation do not affect Adapted Exposure CoVaR beta. These results provide further evidence that Adapted Exposure CoVaR beta estimates the systemic risk exposure of financial institutions, and that these estimates are not sensitive to the underlying cause of a crisis period. Further, they are a first step toward a more general understanding of the determinants of systemic risk exposure.

Given that Adapted Exposure CoVaR beta is the measure which is best suited for forecasting the performance of financial institutions in terms of asset returns, I examine its properties in more detail. First, I find that Adapted Exposure CoVaR beta is successful in forecasting the within-crisis performance of financial institutions at a maximum of one year prior to the onset of a crisis period. Second, this measure is capable of forecasting an institution's returns over periods longer than just the worst one-week period of a crisis. I find that Adapted Exposure CoVaR beta has forecasting ability over cumulative return windows spanning as long as five weeks around the worst week of a crisis. Third, I also find that Adapted Exposure CoVaR beta does not fluctuate simply due to the onset of a crisis, whereas other risk exposure variables tend to increase during a crisis period. This is because Adapted Exposure CoVaR beta is reflecting only an institution's level of systemic risk exposure, rather than changes in the characteristics of an institution brought about by a systemic crisis. Lastly, I examine the performance of

[3] A group of measures focusing on system-wide systemic risk also exists. Though I do not explicitly focus on this literature, the group includes: Lehar (2005); Gray et al. (2007); Adams et al. (2014), Kritzman et al. (2010); and Giglio (2014). In general, these papers propose models which estimate the probability of a crisis throughout the entire system based on individual bank data.

Adapted Exposure CoVaR beta during the entire 1996–2008 period. This allows me to investigate whether the Adapted Exposure CoVaR measure is providing false positives. In other words, this test evaluates whether the measure is exclusively measuring systemic risk, as opposed to also measuring some aspects of systematic risk. If Adapted Exposure CoVaR beta captures only the systemic component of an institution's risk exposure, it should not forecast negative returns during any period other than a systemic crisis period. Indeed, I find that Adapted Exposure CoVaR beta does not forecast the performance of financial institutions during the non-crisis periods of 1996–2008.

In addition to the literature on systemic risk exposure, this paper also ties in with the literature on systemic risk contribution. Models of systemic risk contribution include Tarashev et al. (2009), Chan-Lau (2010), Gray and Jobst (2011), Allen et al. (2012), and Adrian and Brunnermeier (2016). Systemic risk exposure and systemic risk contribution can be linked, as institutions which initially do not cause a crisis but have both high exposure and high contribution measures may add additional stress to the financial system in the event of a crisis. Moreover, some papers in the literature discuss the merits of the systemic risk measures I analyze here. This group includes Lo Duca and Peltonen (2013), Rodríguez-Moreno and Peña (2013), Girardi and Ergün (2013), and Patro et al. (2013), among others. Whereas these papers examine how measures like CoVaR estimate a financial institution's *contribution* to systemic crises, my paper examines how these measures estimate a financial institution's *exposure* to systemic risk conditional on a crisis. Measuring the exposure of financial institutions to systemic risk is important as it estimates the sensitivity of individual financial institutions to a tail event in the financial system.

The remainder of the paper proceeds as follows. Section 2 describes the characteristics of a systemic risk exposure measure. Section 3 presents the measures of systemic risk I compare in this paper, and provides a review of each measure. Section 4 describes the data, while section five presents a discussion of the results. Section 6 investigates the drivers of Adapted Exposure CoVaR beta. Section 7 provides robustness tests, and Section 8 concludes.

2. Characteristics of a systemic risk exposure measure

An effective measure of systemic risk exposure should have three characteristics. I present each characteristic below. I later investigate the performance of systemic expected shortfall, Granger causality, and Adapted Exposure CoVaR in terms of each characteristic.

2.1. Performance forecasting

A measure of institution-level systemic risk exposure is a forecast of a financial institution's sensitivity to a crisis. At a minimum, this condition should be fulfilled immediately prior to the onset of a crisis. However, it will be beneficial if a measure has forecasting ability when estimated well before a crisis period because it will allow for regulators, institution executives, and investors to understand the impact that a systemic crisis would have on an institution well before its onset.

In a systemic crisis period, institutions with high exposure to systemic risk should perform more poorly than institutions with low exposure. Thus, conditional on a crisis period, a lagged measure of systemic risk exposure should be negatively related to future asset or stock returns. Empirically, I focus on lags as short as one week prior to a crisis and as long as four quarters prior to a crisis.

2.2. Exposure forecasting

A second characteristic of a measure of systemic risk exposure is its ability to forecast future systemic risk exposure. This is a useful feature as it will allow the measure to assess which institutions are systemically risky prior to a crisis period. This feature may further provide evidence that a measure is not a proxy for other characteristics of financial institutions. Exposure forecasting may be particularly useful in a practical sense, as, for example, the 2010 Dodd-Frank Wall Street Reform and Consumer Protection Act requires the designation of a list of "systemically important" institutions.

I empirically investigate whether a measure provides a forecast of future exposures by examining the relation between the current measure of systemic risk and its lagged values. If a measure can forecast future exposures, one would expect a positive coefficient estimate for the lagged exposure measure.

2.3. Performance over time

A third characteristic of a systemic risk exposure measure is that it is useful across crises. Systemic crises occur for different reasons. Thus, if a measure is too closely tied to the cause of a single crisis, it will fail to forecast the performance of financial institutions during other crisis periods. This criterion can be evaluated by examining the performance of the systemic risk measures in empirical tests conducted over different systemic crisis periods. I infer that a measure is useful across multiple crisis periods if it is a statistically significant forecasting variable for the performance of financial institutions in both crisis periods.

3. Measures of systemic risk exposure

I compare three methods of estimating systemic risk in terms of the characteristics described above: Adapted Exposure CoVaR, Granger causality (Billio et al., 2012), and systemic expected shortfall (Acharya et al., 2016). These are three major approaches to quantifying institution-level systemic risk exposure in the literature.[4] These measures all estimate the systemic risk an institution is exposed to at a given point in time, but each measure approaches this estimation in a different way. Below, I define each method and discuss how the respective measures describe the systemic risk exposure of an institution.

3.1. Adapted Exposure CoVaR

3.1.1. Definition of CoVaR

Adapted Exposure CoVaR is based on Adrian and Brunnermeier (2016). The authors provide two key measures for determining the systemic risk of an institution. Each measure captures a different aspect of an institution's systemic risk. *Contribution CoVaR* estimates the contribution of a single institution to the overall losses suffered by the entire financial system, given a crisis event. *Exposure CoVaR* provides an estimate of the change in an institution's VaR given an industry-wide systemic crisis. I focus specifically on adapting the Exposure CoVaR measure for use as a forecasting variable.

The authors define Exposure CoVaR (specifically, $\Delta CoVaR_q^{j|s}$) as "institution *j*'s increase in VaR in the case of a financial crisis." I

[4] Several other measure of systemic risk exist. As noted above, many of these measure estimate the contribution of financial institutions to systemic risk of the financial system, and other estimate aggregate systemic risk.

denote the financial system as s. Formally, Exposure CoVaR is given by the qth-quantile of the conditional probability distribution:

$$Pr(X^j \leq CoVaR_q^{j|\mathbb{C}(X^s)} | \mathbb{C}(X^s)) = q \tag{3.1}$$

where X^j is the variable for which the value-at-risk of institution j is defined, $\mathbb{C}(X^s)$ is a tail event within the system, and $CoVaR_q^{j|\mathbb{C}(X^s)}$ is the VaR of an institution conditional on the state of the financial system.[5] The variable q denotes a probability level corresponding to the left tail of the distribution of institution-level asset returns. This value is typically set to 1%. Further, the system's contribution to j, which is in turn j's exposure to the system, is given by:

$$\Delta CoVaR_q^{j|s} = CoVaR_q^{j|X^s = VaR_q^s} - CoVaR_q^{j|X^s = Median^s} \tag{3.2}$$

Empirically, Adrian and Brunnermeier (2016) estimate Exposure CoVaR using quantile regressions (Koenker and Bassett, 1978), which estimate coefficients at the 1% quantile rather than at the mean. First, the authors calculate the week-to-week change in the market value of institution and industry assets. X_j denotes the change in the assets of a financial institution and X_s denotes the change in the assets of the system. Then, denoting a set of macroeconomic conditioning variables (including the VIX, liquidity spread,[6] change in the three-month Treasury bill rate, change in the slope of the yield curve,[7], change in the credit spread[8] weekly equity market return, and one year cumulative real estate sector return[9]) as M_{t-1}, the authors estimate:

$$X_j = \beta^{j|s} X_s + \gamma^{j|s} M_{t-1} + \alpha^{j|s} + \epsilon^{j|s} \tag{3.3}$$

$$X_s = \alpha^s + \gamma^s M_{t-1} + \epsilon^s \tag{3.4}$$

The generated coefficients are then used to estimate the VaR and CoVaR of the institution and the system at the median and q = 1% levels. Finally, $\beta^{j|s}$ is used to calculate Exposure CoVaR:

$$\Delta CoVaR_q^{j|s} = \beta^{j|s}(VaR_t^s(q) - VaR_t^s(50\%)) \tag{3.5}$$

3.1.2. Proposed changes to Exposure CoVaR

As constructed, the estimation method of Exposure CoVaR incorporates all available past information. Thus, it is a useful tool to discern what institution-level variables are closely linked to systemic risk exposure over the full length of a sample period. However, it is not clear how well the measure reflects the systemic risk exposure of an institution at a specific time since there is no reason for exposure to be constant over time for an institution. I thus propose two modifications to estimating Exposure CoVaR compared to the approach used by Adrian and Brunnermeier (2016).

The first modification relates to the estimation of $\beta^{j|s}$. As currently calculated $\beta^{j|s}$ does not vary over time. I allow $\beta^{j|s}$ to vary over time by using data available only over the two years prior to the quarter of estimation.[10] In all regressions that follow, Exposure CoVaR will be calculated using this modified process. This modification thus allows institution-level exposures to change over time. This is a potentially useful innovation because the drivers of systemic risk exposure may vary over time. Thus, rather than use institution-level variables to indirectly forecast systemic risk exposure, the Exposure CoVaR measure may be utilized directly to determine which institutions have the highest levels of systemic risk exposure at a specific time. Despite this change, however, the economic definition of Adapted Exposure CoVaR does not change from its original meaning, as it measures the sensitivity of the performance of financial institutions conditional on a systemic event.

The second modification is to alter the way the market value of the assets of financial institutions is calculated. Adrian and Brunnermeier (2016) calculate the market value of assets as market equity multiplied by book leverage. I propose calculating the market value of assets as (book assets – book equity + market equity), which is a standard definition. The difference between these two approaches can be illustrated with a simple example. Given a distressed institution with market-valued equity equaling 10% of book equity, book leverage of 10, and book equity of \$40 billion; its assets would equal \$400 billion. The first approach values assets at \$40 billion, while the second approach values assets at \$364 billion, which may be a more reasonable approximation. Further, this provides a smoother time-series of asset market values, which will help eliminate large fluctuations in the CoVaR measure over time. I estimate the main results of the paper again, but use the original definition of the market value of firm assets. I find that the CoVaR measure does not forecast performance within *all* crises when this version of assets is used, but rather it is successful during the LTCM crisis but not the Lehman Brothers crisis. These results are reported in Appendix C of the Online Appendix to this paper.

3.1.3. Adapted Exposure CoVaR Beta ($\beta_t^{j|s}$)

$\beta_t^{j|s}$ estimates the exposure of the assets of an institution to a change in the assets of the financial system. Alternatively, Adapted Exposure CoVaR in its entirety provides an estimate of the change in an institution's VaR given its level of exposure. This is because Adapted Exposure CoVaR is the product of $\beta_t^{j|s}$ and the difference between the median state and 1% worst state of the financial system's assets at time t. Thus, Adapted Exposure CoVaR is a measure that increases during crisis periods due to the state of the economy. Rather, a measure of exposure should remain reflective of the institution's specific state at a given time, rather than merely reflective of the state of the overall financial system. Therefore, I use Adapted Exposure CoVaR beta ($\beta_t^{j|s}$) throughout the paper as the primary estimate of systemic risk exposure from the CoVaR family. This measure specifically relates the sensitivity of an institution's assets, rather than the institution's VaR, to changes in the value of the assets of the financial system. Because of this, Adapted Exposure CoVaR beta can be thought of as a measure of the exposure of the value of an institution to a systemic crisis.

3.2. Granger causality

Billio et al. (2012) provides several unique measures for determining the overall systemic risk faced by the financial system, including correlation, principal components analysis, Markov switching regimes, and Granger causality tests. These measures are constructed using monthly return indices of all banks, brokers, insurers, and hedge funds. In general, these measures do not address how an individual institution contributes to overall risk or how systemic risk affects an institution individually. However, the authors modify the Granger causality measure so it may be utilized on an institution-level basis. The modified version of Granger causality measures the inter-connectedness of each bank within the financial system.

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[5] The usual convention is to express VaR as a positive number even though it corresponds to a loss. Adrian and Brunnermeier (2016) do not follow that convention. Thus, their VaR estimates are negative. To avoid confusion, I follow their practice.

[6] The difference between the three-month repo rate and the three-month bill rate.

[7] Measured by the yield-spread between the ten-year Treasury rate and the three-month bill rate.

[8] Between BAA rated bonds and the Treasury rate.

[9] This is defined as the return in excess of the market return for any real estate companies with SIC code 65-66.

[10] Other short lags can be utilized, and produce similar results to those below. In a sensitivity analysis, I find that a two year window is the maximum window one can use for CoVaR and still have reliable performance forecasting. When using a three- or five-year window for CoVaR, the measure does not forecast the Lehman Brothers crisis accurately. These results are reported in Appendix I of the Online Appendix.

Granger causality tests measure linear causality between two time-series (Granger, 1969). Following Billio et al. (2012), linear inter-relationships are represented as:

$$X_t = \sum_{j=1}^{m} a_j X_{t-j} + \sum_{j=1}^{m} b_j Y_{t-j} + \epsilon_t \quad (3.6)$$

$$Y_t = \sum_{j=1}^{m} c_j X_{t-j} + \sum_{j=1}^{m} d_j Y_{t-j} + \eta_t \quad (3.7)$$

Within the context of this test, *Y Granger causes X* when b_j is not equal to zero. Similarly, when c_j is not equal to zero, the test implies that *X Granger causes Y*. However, when both b_j and c_j are not equal to zero, a bi-directional relationship exists, and it is not necessarily clear which variable causes the other. Note that these tests address *linear* relations between institutions. Even if the test is inconclusive, a non-linear relation may still exist.

To apply this test to the financial system, the authors use the time-series of daily stock returns to determine which institutions Granger cause the returns of others. Higher levels of interconnectedness can imply that either an institution is exposed to higher levels of systemic risk, since it is connected to more institutions; or that an institution contributes more to systemic risk levels, as it drives the performance of other institutions.

I utilize this measure by calculating the inter-connectedness of each of the top 25 banks, brokers, and insurance companies on a quarterly basis during the period 1996–2008 using the previous three years of returns, following the authors' method. I calculate the number of other institutions that a single institution is exposed to. That is, I sum the number of other institutions which Granger cause the returns of the single institution. This allows the Granger causality measure to be used as a measure of exposure to systemic risk rather than contribution to systemic risk. I require a 1% statistical significance level for Granger causality.

This measure differs from Adapted Exposure CoVaR beta in that it examines institution-level connections rather than how one institution is influenced by the system as a whole.

3.3. Systemic expected shortfall

Acharya et al. (2016) provides another measure for determining the systemic risk exposure of an institution. The *systemic expected shortfall* (SES) of an institution describes its "propensity to be undercapitalized when the system as a whole is undercapitalized." The authors theoretically derive the two key components of SES: marginal expected shortfall (MES) and Leverage (LVG), and use them to proxy for the total SES measure. I follow the same methodology in this paper.

MES measures the average return of financial institutions on days when the market as a whole is in the tail of its return distribution. Following Acharya et al. (2016), MES is calculated at the 5% level[11] over the past return data:

$$MES_{5\%} = \frac{1}{\#days} \sum_{t:system\ in\ 5\%\ tail} R_t \quad (3.8)$$

where R_t represents the daily returns of the institution, and the summation is conditional on the left-tail of the market's return distribution. Further, the authors estimate leverage using the following approximation:

$$LVG = \frac{\text{book assets} - \text{book equity} + \text{market equity}}{\text{market value of equity}} \quad (3.9)$$

SES is different from Adapted Exposure CoVaR beta and Granger causality in how it attempts to measure systemic risk. SES examines how an institution is affected by the entire market rather than how individual institutions affect each other, like Granger causality does. Further, SES utilizes stock returns while Adapted Exposure CoVaR beta uses changes in the market value of an institution's assets. Although both SES and Adapted Exposure CoVaR beta examine the impact that the system has on an institution, they do so in different ways. The MES component of SES follows a calculation method similar to that of expected shortfall. The modification MES makes to expected shortfall allows it to estimate how individual institutions' stock returns react to those of the entire market. Because MES compares how an institution performs relative to the performance of the stock market, it may not provide insight beyond that provided by the CAPM beta. While it is true that MES is a measure of tail dependence and the CAPM beta is a linear relationship, the correlation between the two variables is greater than 68% for the entire sample period, and over 76% during the 2006–2008 subsample (correlations are presented in Table 2).

Finally, Adapted Exposure CoVaR beta uses quantile regressions in its estimation process, which estimates values at the 1% level, whereas other regression methods concentrate on the mean. This allows the measure to estimate systemic risk exposure in terms of the left-tail of the distribution. In turn, this lets Adapted Exposure CoVaR beta, to an extent, address the fact that tail events are rare. Rather than simply project how institutions respond to system-wide shifts, the measure specifically examines how institutions respond to system-wide shifts *during tail events*. This provides specific insight for crisis periods. MES also concentrates on the left tail of the return distribution, examining the 5% worst return days for the market. Granger causality, however, does not focus on the left tail of the distribution, as no distinction regarding the severity of stock returns is made in its estimation process.

4. Data

Accounting data and stock returns are collected from Compustat and CRSP, respectively. I collect VIX, LIBOR and repo rate data from Bloomberg. Finally, Treasury rates and the Baa corporate bond rate are collected from the Federal Reserve. Accounting data are used in calculating the SES measure LVG, Adapted Exposure CoVaR, and control variables (namely, institution size and weekly changes in asset market values). I also use accounting data to construct my sample on a quarterly basis. Starting with the first quarter of 1995, I calculate the five-year moving average of assets for all banks, insurance companies, and brokers over the previous 20 quarters.[12] Then, the institutions are ranked using this size measure, and the largest 25 institutions in each category are kept for analysis.[13] The moving average method prevents institutions from repeatedly transitioning in and out of the sample over time. My sample thus contains a total of 3900 institution-quarter observations over the time period of 1996–2008. There are 156 different institutions in the sample, of which 50 are banks, 50 are insurers, and 56 are brokers. Because banks, brokers, and insurers may be connected (e.g.

[11] The choice of 5% as the threshold for MES follows Acharya et al. (2016) directly. I also estimate MES with a 1% threshold and repeat the analysis. I find that the results are not materially different. As such, I choose to use MES at the 5% level to keep in line with the choice of Acharya et al. (2016).

[12] Following Billio et al. (2012), I define banks as institutions with SIC codes between 6000 and 6199, brokers as institutions with SIC codes between 6200 and 6299, and insurers as institutions with SIC codes between 6300 and 6499.

[13] I have also examined the sample consisting of all financial institutions regardless of size. Results presented below hold for this larger sample.

as counterparties), it is important to examine each of these three sectors of the financial system. I follow Billio et al. (2012) in choosing the largest 25 from each sector. Return data from CRSP are used in the computation of all measures and control variables. Finally, VIX, LIBOR, and interest rate data are used as conditioning variables in estimating Adapted Exposure CoVaR.

Systemic risk measures are computed at a quarterly level. The MES component of the SES measure is not feasible at a frequency shorter than quarterly, as fewer observations are insufficient to find a 5% threshold for low returns.[14] The Granger causality measure, which also uses daily returns, may be influenced by noise in the data if it is estimated over periods shorter than one quarter. The Adapted Exposure CoVaR measure is calculated on a quarterly basis using weekly data. This is feasible due to the fact that the measure incorporates weekly macro level variables along with week-to-week changes in the market values of the assets of financial institutions.[15]

Table 1 presents summary statistics describing the systemic risk exposure measures used in the analysis below. Some measures of systemic risk display a noticeable increase during years containing a crisis period. For example, the average Adapted Exposure CoVaR changes from −10.08% one year before the 1998 financial crisis to −26.34% during the crisis; and from −11.91% prior to the 2008 financial crisis to −24.23% during it. A similar pattern holds for MES, value-at-risk (VaR), and expected shortfall (ES), as each variable indicates that the systemic risk exposure of financial institutions increased during the crisis periods. Alternatively, the average level of the Adapted Exposure CoVaR beta increases from 0.15 in 1996 to 0.24 in 1998, however, its average level decreases from 0.23 in 2006 to 0.16 in 2008. Further, levels of Granger causality do not fluctuate much in the 1996–1998 period, but experience a large shock during 2008. Average 1% Granger causality increases from 1.78 in 2006 to 5.12 in 2008.

The standard deviations of the measures of systemic risk exposure are not trivial. Especially immediately prior to and within a crisis, it should be expected that some institutions will have exceptionally high exposures to systemic risk. As seen in Table 1, the standard deviations of Adapted Exposure CoVaR, MES, and Granger causality are markedly larger in 1998 (2008) than in 1996 (2006). Accordingly, it is natural to wonder if extreme values may be driving the results presented below, namely for the Adapted Exposure CoVaR measure. To this end, I repeat the key analysis below using winsorized values of Adapted Exposure CoVaR beta (unreported), and find that the results do not change.

Table 2, panel A presents the correlation coefficients between all measures of systemic risk exposure and all control variables used in the analysis over the 1996–2008 period. For the most part, different measures of systemic risk exposure are uncorrelated. This is surprising, as it indicates that each measure is quantifying something different, even though each aims to estimate the systemic risk exposure of the institution.[16] One reason for this difference may be due to each measure's construction. First, note that MES has a high correlation with all of the control variables. This is to be expected, as the estimation method for MES is similar to that of ES or VaR, but with a slight modification. Moreover, MES is a measure that relates the stock returns of an individual institution to the stock returns of the market, like beta. The construction of MES thus leads to a high correlation between it and beta. The high correlation between MES and the control variables then indicates that MES may simply be a proxy for the overall riskiness of the institution rather than a measure of the systemic component of the risk exposure of financial institutions. Additionally, the connections measured by Granger causality could, for instance, be unrelated to the systemic risk exposure of financial institutions.

I calculate separately correlations for only the time periods that pertain to crisis periods. As to be expected, correlation among the control variables remains high. This pattern holds true for variables in both subsamples, except beta. During the 1996–1998 period, beta has a lower correlation with other control variables relative to its correlation during the entire 1996–2008 period. Further, during the 2006–2008 period, beta's correlation with other control variables is much higher relative to its correlation with control variables during the 1996–2008 period. Due to their generally high correlations with each other, I will include only one control variable in a given regression.

Additionally, I plot the time-series of the quarterly sample average of systemic risk exposure variables in Figs. 1 and 2. Fig. 1 corresponds to the 1996–1998 time period, while Fig. 2 corresponds to the 2006–2008 time period. In both time periods, Adapted Exposure CoVaR displays a sharp decrease (which represents an increase in institution VaR) near the onset of the systemic crisis. Specifically, this overall increase in systemic risk exposure appears in the third quarter of 1998 — directly corresponding to the Russian/LTCM crisis — where average Adapted Exposure CoVaR shifted from −21.43% to −31.15%. Moreover, during the 2006–2008 period, Adapted Exposure CoVaR begins a noticeable decline between the second and third quarters of 2007, as its average value shifts from −11.40% to −18.44%. A further decline is observed during the 2008 calendar year, as average Adapted Exposure CoVaR shifts from −20.17% in the third quarter to its peak of −37.79% in the fourth quarter. The second shift directly corresponds to the events of the Lehman Brothers collapse in late 2008. In both crisis periods, the Adapted Exposure CoVaR measure signals an increase in the value-at-risk of financial institutions brought on by each institution's exposure to systemic risk. In comparison, Adapted Exposure CoVaR beta does not move sharply prior to a crisis period.

Following the first quarter of 1996, the Granger causality measure is relatively stable. This measure increases from its low in the fourth quarter of 1997 of 2.04 to 3.39 in the fourth quarter of 1998. Average Granger causality increases in the first quarter of 2008 to 2.34, and peaks in the fourth quarter of 2008 at 5.40. Finally, during the 1997–1998 period, MES sharply declines twice. First, between the third and fourth quarters of 1997, MES declines from −1.68% to −2.95%; and between the second and third quarters of 1998, average MES declines from −1.99% to −4.59%. During the 2007–2008 period, average MES has one major decline. Between the second and third quarters of 2008, average MES declines from −3.29% to −11.28%. Because decreases in the value of MES represent increases in systemic risk exposure, these shifts signal an overall increase in systemic risk exposure during both crisis periods.

[14] Results are robust to calculating MES with different estimation windows, including a two-year window. This is an important finding, as MES calculations with short windows can produce volatile estimates.

[15] Not only do I include weekly changes in the market value of equity, but I also include weekly changes in book assets and book equity by interpolating them over each quarter. This methodology follows Adrian and Brunnermeier (2016). Note that no other variable is interpolated at any point in the construction of the measures of systemic risk exposure. This practice does not introduce a look-ahead bias to the analysis below as for all regressions, I use lagged measures of systemic risk exposure.

[16] Appendix A presents a listing of the ten riskiest banks and insurers during the 2008 Lehman Brothers crisis period in terms of each measure of systemic risk exposure. The ranking of the riskiest financial institutions differs for each measure. The Marshall & Ilsley Corporation (M&I) is listed as the bank with the largest systemic risk exposure during this period, according to the Adapted Exposure CoVaR methodology ($\beta_t^{j|s} = 0.28$). Alternatively, MES ranks the CIT Group (MES = 19.11%) and Granger causality ranks Citigroup (Granger = 17) as the riskiest banks during this period. The difference in the ranking of financial institutions provided by each measure is further evidence that each measure is quantifying systemic risk exposure in a different way. The Online Appendix contains a list of all banks used within the cross-sectional tests below.

Table 1
Summary statistics.
This table presents summary statistics for key variables used in the analysis below. I report summary statistics for the two crisis periods that are studied: the Russian/LTCM crisis of the late 1998 and the Lehman Brothers crisis of late 2008. Adapted Exposure CoVaR corresponds to the Adapted Exposure CoVaR of a institution at the 1% level, which measures the change in institution VaR given a system-wide crisis. This measure differs from Adrian and Brunnermeier's (2016) Exposure CoVaR measure, as the coefficient on system returns is allowed to change over time. Exposure CoVaR Beta refers to the $\beta_t^{j|s}$ coefficient that comes from the Adapted Exposure CoVaR methodology. This coefficient measures the sensitivity of the assets of a financial institution to the assets of the financial system. MES corresponds to the marginal expected shortfall, which measures the average institution stock return during the worst 5% days of market returns, while LVG corresponds to institution leverage. 1% Granger corresponds to the number of other institutions' returns that are *Granger caused* by a given institution at the 1% level. Assets corresponds to the book value of the institution's assets, measured in billions of dollars. VaR represents the institution's value at risk, measured in terms of stock returns at the 5% level. ES represents the institution's expected shortfall, measured in terms of stock returns at the 5% level. All variables are measured at a quarterly frequency and averaged over the year.

Year	Adapted Exposure CoVaR	Exposure CoVaR beta	SES family		1% Granger	Control variables		
			LVG	MES		Assets (Billions)	VaR	ES
Panel A: Pre-crisis and Russian/LTCM crisis of 1998 Q4								
1996 Mean	−.1008108	.1552	11.86087	−.0174462	3.3673	57.1	−.0225152	−.0299876
Std. dev.	.1465407	.2221	7.965255	.0103338	3.2898	71.4	.0077097	.0095843
1997 Mean	−.2011936	.2093	12.46703	−.0214265	2.6281	65.8	−.0263114	−.0354645
Std. dev.	.4406193	.3797	9.166354	.0122856	3.2355	82.6	.0079624	.0119289
1998 Mean	−.2634084	.2447	12.24556	−.027339	3.5700	77.4	−.0365708	−.0472452
Std. dev.	.3949794	.3574	9.841779	.0186348	4.3555	104.0	.0185756	.0245932
Panel B: Subprime crisis, 2006–2008								
2006 Mean	−.1191412	.2301	10.44934	−.0125143	1.7780	196.0	−.0186382	−.0259296
Std. dev.	.16364	.3135	6.71058	.0091428	2.5396	336.0	.0086383	.0139165
2007 Mean	−.1506515	.2051	10.68748	−.0286838	1.9182	234.0	−.0306426	−.0397134
Std. dev.	.1666067	.2300	7.223385	.0163687	2.1338	402.0	.0192116	.0255071
2008 Mean	−.2423113	.1676	10.84056	−.0749532	5.1184	232.0	−.076774	−.1039189
Std. dev.	.3475484	.2157	7.368776	.0542315	5.8228	437.0	.04776	.0657753

Table 2
Correlation matrix of systemic risk measures.
This table presents the correlation coefficients between each set of systemic risk measures and control variables used in regressions. I report these tables for the entire sample period of 1996–2008, the Russian/LTCM crisis period of 1996–1998, and the Subprime crisis period of 2006–2008. Adapted Exposure CoVaR Beta refers to the $\beta_t^{j|s}$ coefficient that comes from the Adapted Exposure CoVaR methodology. This coefficient measures the sensitivity of the assets of a financial institution to the assets of the financial system. MES corresponds to the marginal expected shortfall, which measures the average institution stock return during the worst 5% days of market returns, while LVG corresponds to institution leverage. Granger corresponds to the number of other institutions' returns that are *Granger caused* by a given institution at the 1% level. Control variables include institution CAPM beta and stock return volatility. Expected shortfall (ES) is a control which measures the average of all returns in the left tail (5%) of an institution's return distribution. Value-at-risk (VaR) is a control which measures an institution's stock returns at the 5% level of its return distribution. All variables are measured at a quarterly frequency.

Variables	Adapted Exposure CoVaR beta	SES family		Granger	Control variables			
		LVG	MES		VaR	ES	Vol.	Beta
Panel A: 1996–2008								
Adapted Exposure CoVaR Beta	1.000							
LVG	0.346	1.000						
MES	0.100	−0.086	1.000					
Granger	0.006	0.005	−0.180	1.000				
VaR	0.126	−0.086	0.721	−0.169	1.000			
ES	0.101	−0.058	0.735	−0.170	0.939	1.000		
Vol.	−0.102	0.076	−0.654	0.183	−0.890	−0.910	1.000	
Beta	−0.078	0.142	−0.684	0.132	−0.526	−0.518	0.539	1.000
Panel B: 1996–1998								
Adapted Exposure CoVaR Beta	1.000							
LVG	0.284	1.000						
MES	0.056	−0.150	1.000					
Granger	−0.042	0.003	−0.028	1.000				
VaR	0.090	−0.164	0.626	−0.147	1.000			
ES	0.081	−0.120	0.658	−0.131	0.927	1.000		
Volatility	−0.071	0.147	−0.518	0.133	−0.852	−0.882	1.000	
Beta	0.027	0.261	−0.576	0.017	−0.009	−0.271	0.279	1.000
Panel C: 2006–2008								
Adapted Exposure CoVaR Beta	1.000							
LVG	0.379	1.000						
MES	0.173	−0.109	1.000					
Granger	−0.115	0.088	−0.357	1.000				
VaR	0.186	−0.109	0.857	−0.314	1.000			
ES	0.154	−0.082	0.873	−0.337	0.956	1.000		
Vol.	−0.183	0.080	−0.874	0.329	−0.950	−0.967	1.000	
Beta	−0.247	0.172	−0.766	0.146	−0.771	−0.764	0.793	1.000

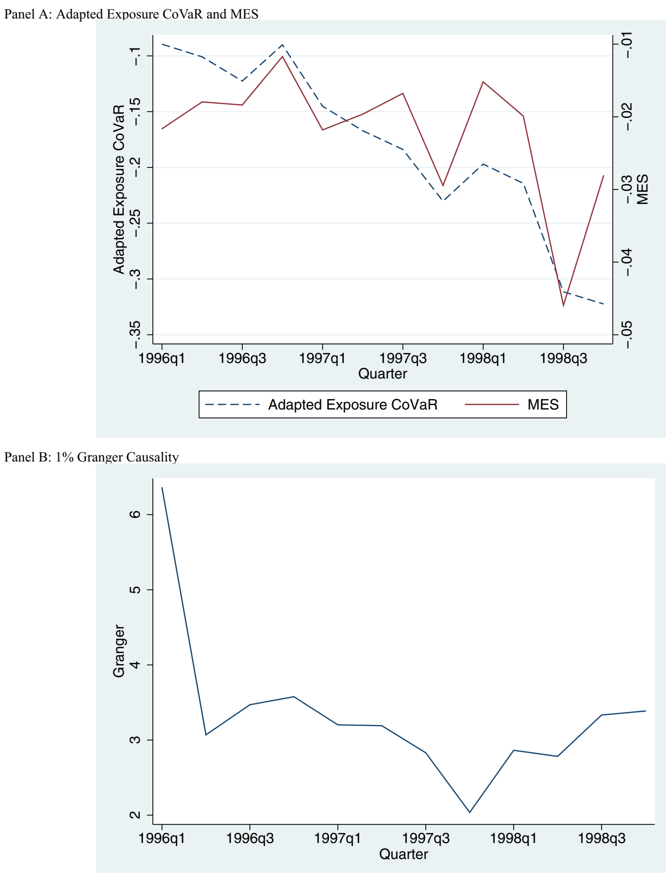


Fig. 1. Systemic measures during the Russian/LTCM crisis period: 1996–1998. These figures present each of the three measures of systemic risk that I examine: Adapted Exposure CoVaR, Granger causality, and SES, plotted as a time-series during the Russian/LTCM crisis. Adapted Exposure CoVaR calculates the percentage change in an institution's Value-at-Risk given a shift in the state of the financial system from its median state to its 1% worst state. Average Adapted Exposure CoVaR measures by quarter are plotted below. Granger causality measures the causal relation between the returns of two institutions. One institution is said to *Granger Cause* the returns of another if there is a significant (at the 1%) level relation between lagged returns of one institution and current returns of the other, but not vice-versa. The average number of other institutions that a given institution Granger-Causes in one quarter is plotted below. Systemic expected shortfall (SES) is proxied for below by the marginal expected shortfall (MES) measure. Together with Leverage (LVG), MES is considered to be a core component of calculating the expected SES of an institution for a given time period. MES measures the average return of an institution during the worst 5% of return days for the overall market during the past calendar year. Average MES by quarter is plotted below.

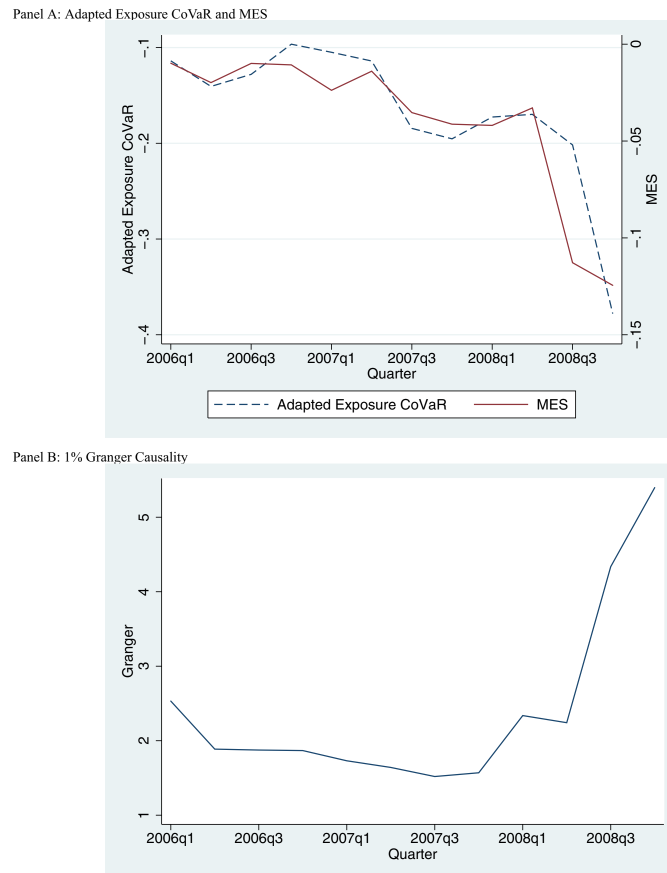
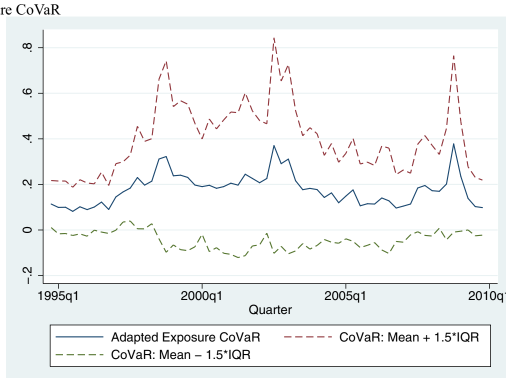


Fig. 2. Systemic measures during the Lehman Brothers crisis period: 2006–2008. These figures present each of the three measures of systemic risk that I examine: Adapted Exposure CoVaR, Granger causality, and SES, plotted as a time-series during the Lehman Brothers crisis. Adapted Exposure CoVaR measures the sensitivity of an institution's Value-at-Risk to a shift in the state of the financial system from its median state to its 1% worst state. Average Adapted Exposure CoVaR measures by quarter are plotted below. Granger causality measures the causal relation between the returns of two institutions. One institution is said to *Granger cause* the returns of another if there is a significant (at the 1%) level relation between lagged returns of one institution and current returns of the other, but not vice-versa. The average number of other institutions that a given institution Granger-causes in one quarter is plotted below. Systemic expected shortfall (SES) is proxied for below by the marginal expected shortfall (MES) measure. Together with Leverage (LVG), MES is considered to be a core component of calculating the expected SES of an institution for a given time period. MES measures the average return of an institution during the worst 5% of return days for the overall market during the past calendar year. Average MES by quarter is plotted below.

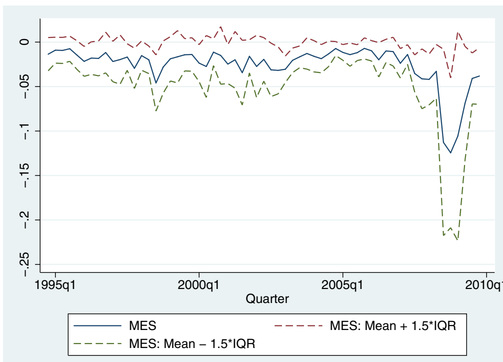
Fig. 3 presents all three measures plotted over the entire time period from 1995 to 2010. This figure expands Figs. 1 and 2, and inverts the CoVaR measure to highlight its negative correlation with MES, and to align it more closely with traditional VaR measures, which are conventionally expressed as positive numbers. Although informative, simply looking at Figs. 1 and 2 do not allow for the assessment of whether the increases in each measure are truly extreme during the crisis periods or if they are not different from any other non-crisis period. In each figure, I plot the mean value of the systemic risk exposure measures along with bands which represent 1.5 times the inter-quartile range. These bands represent the cutoff for outliers in the data. In panel A, the Adapted Exposure CoVaR measure reaches local maximums in 1998, 2002, and 2008, where 1998 and 2008 represent the crisis periods I study in this paper. The increase in 2002 is due to the market crisis surrounding September 11, 2001 and the dot.com bubble. Panel B shows that the MES measure reaches an overall minimum in 2008 and several local minimums in the late 1990's and early 2000's, with the largest of these occurring in 1998. For both MES and especially CoVaR, I find that the measures tend to increase the most when there is a financial crisis. Panel C displays the Granger causality measure. This measure reaches its maximum in 2009, well after the collapse of Lehman Brothers. Moreover, the measure does not increase markedly during any other period in the sample.

Fig. 4 presents a time-series of the mean Adapted Exposure CoVaR measure plotted against the mean Adapted Exposure CoVaR beta ($\beta_t^{j|s}$) between 1996 and 2008. $\beta_t^{j|s}$ is the more relevant measure of exposure that comes from the Adapted Exposure CoVaR methodology. Adapted Exposure CoVaR represents the change in an institution's value-at-risk given a change in the assets of the financial system, whereas Adapted Exposure CoVaR beta estimates only the level of exposure the assets of an institution have to system-wide events. For this reason, the Adapted Exposure CoVaR measure will tend to peak during

Panel A: Adapted Exposure CoVaR



Panel B: MES



Panel C: 1% Granger Causality

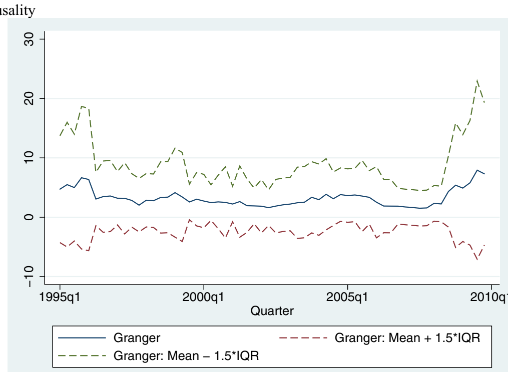


Fig. 3. Full time-series plots of systemic risk exposure measures. These figures present each of the three measures of systemic risk that I examine: Adapted Exposure CoVaR, Granger causality, and SES, plotted as a time-series from 1995 to 2010. Adapted Exposure CoVaR measures the sensitivity of an institution's Value-at-Risk to a shift in the state of the financial system from its median state to its 1% worst state. Average Adapted Exposure CoVaR measures by quarter are plotted below. Granger causality measures the causal relation between the returns of two institutions. One institution is said to *Granger Cause* the returns of another if there is a significant (at the 1%) level relation between lagged returns of one institution and current returns of the other, but not vice-versa. The average number of other institutions that a given institution Granger-Causes in one quarter is plotted below. Systemic expected shortfall (SES) is proxied for below by the marginal expected shortfall (MES) measure. Together with Leverage (LVG), MES is considered to be a core component of calculating the expected SES of an institution for a given time period. MES measures the average return of an institution during the worst 5% of return days for the overall market during the past calendar year. Average MES by quarter is plotted below.

crisis periods due to a market-wide increase in asset volatility, even if the institution's level of exposure, as measured by Adapted Exposure CoVaR beta, remains unchanged. Note that in this figure, the overall level of exposure ($\beta_t^{i|j}$) does not display the same within-crisis peaks that Adapted Exposure CoVaR does.

Adapted Exposure CoVaR vs. CoVaR Beta, 1996-2008

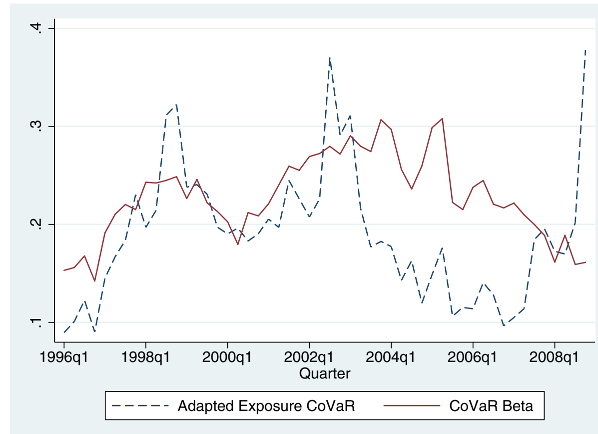


Fig. 4. Adapted Exposure CoVaR vs. Adapted Exposure CoVaR Beta. This figure presents the time-series of Adapted Exposure CoVaR and Adapted Exposure CoVaR beta ($\beta_t^{i|s}$) between 1996 and 2008. Adapted Exposure CoVaR measures the change in institution VaR given a systemic event, and allows the beta coefficient to change over time, unlike the Exposure CoVaR measure proposed by Adrian and Brunnermeier (2016). Adapted Exposure CoVaR is presented here as its absolute value, thus, a higher value represents a riskier institution. Adapted Exposure CoVaR beta is the coefficient from the 1% quantile regression that is estimated within the Adapted CoVaR methodology. This regression estimates the sensitivity of institution assets to a change in system-wide assets by regressing the systems week-over-week change in assets on an institution's week-over-week change in assets. Data from only the previous two years is incorporated in the regression.

5. Results

5.1. Systemic risk measures forecasting the performance of financial institutions

I evaluate first whether systemic risk exposure measures can forecast how an institution will be affected by a crisis. For this set of tests, I regress within-period changes in the market value of the assets of financial institutions on each systemic risk measure. Each of the three measures is estimated as of the quarter before the crisis begins. Based on the characteristics presented in Section 2, a measure of systemic risk exposure should forecast that high-risk institutions experience poor within-crisis performance, relative to their peers. I use weekly changes in the market value of the assets of financial institutions as the dependent variable for this set of tests, as the value of assets is directly related to the solvency of an institution.

The systemic events I study take place during 1998 and 2008. It is important to note that these are the only two *systemic* crises in the United States for which data is available to study. The choice of these two crisis periods follows previous work (e.g. Fahlenbrach et al., 2012), which studies the LTCM and Lehman Brothers crisis periods directly. While the CoVaR and MES measures increase during other points in time, it may not be the case that they can effectively forecast firm performance during these non-systemic periods. Adapted Exposure CoVaR and MES are measures of *systemic* risk exposure, and thus, testing them in non-systemic crisis periods is not necessarily a direct test of their abilities to predict firm performance conditional on a systemic crisis.

For each crisis period, I examine the one-week period in which the market was in its greatest period of distress.[17] The 1998 crisis period corresponds to the Russian/LTCM crisis, where I consider the week of August 24 - 28, 1998. During this week, the U.S. stock

[17] In robustness tests, I examine cumulative return periods longer than one week. These results are reported in the Online Appendix.

market experienced a 4.43% decline. By the end of this week, LTCM's net asset value dropped by 44%, and its leverage ratio was 55:1 (Fahlenbrach et al., 2012). Further, this is the week immediately following the Russian Government's default on domestic debt (Chiodo and Owyang, 2002). As a result, fears of a default at LTCM began to build, as this event would be troublesome for large U.S. banks that were among LTCM's creditors or counterparties. Additionally, the S&P Financials Index experienced a decline of 8.29% during this week, which was the worst weekly return of the 1998 calendar year.

During the subprime crisis period of 2008, I examine the week of October 6–10, 2008. The broad market, during this week, fell 24.16%. Perhaps more importantly, the S&P Financials Index declined by 22.38%, which was its largest decline to that point in the calendar year. Moreover, the TED Spread, which is a funding-market indicator, reaches a peak of 4.58% on October 10, which is its highest value during 2008. This data corresponds to the aftermath of the Lehman Brothers collapse, and was reported as the worst week in 112 years for the Dow Jones Industrial Average (Paradis, 2008). Moreover, this crisis was unlike other episodes which precede it. During this week, the Federal Reserve announced a $900 billion provision in short-term cash loans for banks, emergency lending of $1.30 trillion to non-financial companies, and a reduction in interest rates of 0.50%. Further, President George W. Bush considered allowing government ownership stakes in private banks. In both crisis periods, the events which transpired were unique to systemic crises, and are not common to other non-systemic crises.

In regressions presented in Tables 3 and 4, I estimate the following specification:

$$Return_{i,t} = \alpha + \gamma(Systemic_{i,t-1}) + \beta(Controls_{i,t-1}) + \lambda(Sector_i) + \epsilon_{i,t} \quad (5.1)$$

$Systemic_{i,t-1}$ represents the vector of systemic risk terms, which includes **Adapted Exposure CoVaR beta**, **standard CoVaR beta**, **MES**, **LVG**, and **Granger causality**; $Controls_{i,t-1}$ represents the vector of control variables, which includes an institution's CAPM beta, volatility, 5% expected shortfall (ES), 5% value-at-risk (VaR)[18], institution size measured by the natural logarithm of assets, and prior period changes in asset values[19]; finally, $Sector_i$ represents a set of three dummy variables, each taking a value of one if a given institution is a bank, broker, or insurer, respectively. Note that I do not include variables from the real economy (i.e. inflation or unemployment) in these regressions, as there is no variation in these measures across institutions. Because asset and stock returns may exhibit clustering in their volatility (i.e. the ARCH-GARCH effect), all regressions are presented with Huber–White robust standard errors.

ES and VaR are two common risk management measures that I use as control variables to account for an institution's overall level of risk exposure. Both variables are calculated in terms of stock returns. VaR is the loss that will not be exceeded at some specified confidence level, α (Hull, 2009). For all calculations, I set α at the 5% level, although results are robust to their estimation at the 1% level. Thus, VaR is calculated as the fifth percentile of the daily return distribution for a given institution in a given quarter. Additionally, ES is the expected value of losses, conditional on the institution being in the tail of its return distribution (Hull, 2009). Thus, I estimate the ES of an institution by averaging all returns falling below the fifth percentile of its distribution of daily returns within a given quarter. Lastly, the CAPM beta is the coefficient on the market return from the CAPM methodology. I estimate the CAPM beta with different rolling windows, and find that results are robust to the estimation of beta up to the same two-year window in which Adapted Exposure CoVaR beta is calculated.

The first set of results (Table 3) presents tests pertaining specifically to the 2008 Lehman Brothers crisis period. Regressions (1) through (5) incorporate the systemic risk exposure measures of interest and basic controls to account for institution size and prior week returns as independent variables. Regressions (6) through (11) include all measures together, and add a set of controls to account for different traditional measures of an institution's risk exposure.[20] Note, however, that MES is not included in regressions (8)–(11), as it is highly correlated with the control variables used in each regression. Each regression includes institution fixed effects which control for whether an institution is a bank, broker, or insurer. I estimate here the ability of systemic risk exposure measures to forecast asset returns one quarter prior to the crisis. The dependent variable in all regressions is the institution's asset return.

Adapted Exposure CoVaR beta is negatively related to future crisis returns, and is statistically significant at the 1% level in all regressions. This result holds regardless of which control variables and other measures of systemic risk exposure are included in a regression. This relation implies that riskier institutions experience lower returns during the crisis period. The results imply that a one standard deviation increase in the systemic risk exposure of an institution implies a 1.60% decrease in an institution's asset returns during the following week. Economically, this is a large decrease in the performance of an institution for a shift in its systemic risk exposure. In my sample, the average decrease in an institution's market value of assets is 4.40% during the worst week of the crisis. Thus, the shift related to a one standard deviation increase in systemic risk exposure corresponds to a 36.36% decrease in institution performance beyond the mean return. Moreover, the coefficient on Adapted Exposure CoVaR beta remains similar in magnitude despite the addition of MES, LVG, Granger causality, and control variables. Further, the R^2 for regression (1), which includes Adapted Exposure CoVaR beta (54.56%) is larger than that of regressions (2)–(5), which include standard CoVaR beta (47.0%), MES (44.9%), LVG (53.9%), or Granger causality (44.8%). This indicates that Adapted Exposure CoVaR beta is generally explaining a larger portion of the performance of financial institutions than competing measures and control variables. I also measure CoVaR as suggested by Adrian and Brunnermeier (2016), that is, using the entire time series of available data.[21] This standard CoVaR beta is included in regressions (2) and (7). For the 2008 crisis, the standard CoVaR beta measure is not a statistically significant determinant of within crisis performance. This is evidence to suggest that Adapted Exposure CoVaR beta is an improvement to the original CoVaR methodology.

MES and LVG do not perform as well as Adapted Exposure CoVaR beta. Coefficients from regressions (3) and (4) indicate that neither MES nor LVG forecast negative returns for institutions with higher systemic risk exposures (note that the MES measure denotes riskier institutions by lower negative values). Though it should be noted

[18] I choose 5% for both VaR and ES so as to ensure a large enough tail from which to estimate the variables. The results presented below, however, are robust to the choice of 1% for VaR and ES.

[19] Results are robust to the inclusion of asset returns lagged over longer periods.

[20] I do not report results using all controls simultaneously, since they are highly correlated. However, in unreported results, I find that the results presented here are robust to the inclusion of all control variables at once.

[21] Note that the proposed change in the definition of the market value of firm assets impacts the CoVaR calculation as well. I find that CoVaR, calculated with the original definition of the market value of firm assets, forecasts returns during the 1998 crisis, but not during the 2008 crisis. Moreover, changing this definition changes the characteristics of the measure. As such, the standard CoVaR beta is neither mean- nor order-preserving relative to Adapted Exposure CoVaR beta.

Table 3
Forecasting returns during the Lehman Brothers crisis — one quarter prior.
This table presents results of regressions which use systemic risk measures to forecast future asset returns during the 2008 Lehman Brothers crisis period. Specifically, this table examines the week of October 6–10, 2008. Return data is calculated as the week-over-week change in the market value of assets, and the dependent variable is the institution's asset return during the week. Adapted CoVaR Beta is the institution's Adapted Exposure CoVaR beta, $\beta_t^{j|s}$. This measures the sensitivity of the market value of the institution's assets to shifts in the market value of the assets of the financial system. CoVaR Beta is the standard version of the Exposure CoVaR measure, which uses all available past data. MES measures the average return of the institution during the 5% worst days of market returns, while Granger causality measures the level of interconnectedness between one institution and all others. Both MES and Granger are measured at a quarterly level. Included as controls are one-week lagged asset returns; and one-quarter lagged assets, beta, volatility, value-at-risk, and expected shortfall measures. Fixed Effects which account for whether an institution is a bank, broker, or insurer are also included.
t statistics in parentheses.
* $p<0.10$; ** $p<0.05$; *** $p<0.01$.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Adapted CoVaR beta_{t-1}	−0.103***					−0.0857***		−0.0901***	−0.0883***	−0.0874***	−0.0875***
	(−3.42)					(−2.89)		(−3.12)	(−3.11)	(−3.06)	(−3.03)
CoVaR Beta_{t-1}		−0.0359					−0.0182				
		(−1.10)					(−0.51)				
MES_{t-1}			−0.0453			−0.0351	−0.00407				
			(−0.73)			(−0.51)	(−0.05)				
LVG_{t-1}				0.00309***		0.00233***	0.00284***	0.00220***	0.00217***	0.00214***	0.00223***
				(3.59)		(2.92)	(2.67)	(2.74)	(2.85)	(2.73)	(2.96)
Granger_{t-1}					0.000356	0.000279	0.0000325	0.000300	0.000296	0.000394	0.000258
					(0.68)	(0.55)	(0.05)	(0.71)	(0.73)	(0.97)	(0.61)
Beta_{t-1}								0.00565			
								(1.41)			
Volatility_{t-1}									0.244**		
									(2.47)		
VaR_{t-1}										−0.137**	
										(−2.23)	
ES_{t-1}											−0.0800*
											(−1.87)
Asset Returns_{t-1}	0.0997	0.0753	0.0740	0.0931	0.0732	0.114	0.0937	0.117	0.118	0.119	0.117
	(1.49)	(1.43)	(1.45)	(1.58)	(1.45)	(1.56)	(1.53)	(1.62)	(1.62)	(1.63)	(1.58)
$\ln(\text{Assets})_{t-1}$	0.00837***	0.00991***	0.0103***	0.000913	0.0104***	0.000917	0.00132	0.000680	0.000791	0.000605	0.000719
	(3.50)	(3.19)	(3.58)	(0.27)	(3.83)	(0.28)	(0.38)	(0.21)	(0.25)	(0.19)	(0.22)
Constant	−0.225***	−0.273***	−0.293***	−0.0821	−0.292***	−0.0682	−0.0887	−0.0717	−0.0774	−0.0672	−0.0690
	(−3.58)	(−3.27)	(−4.07)	(−1.00)	(−4.17)	(−0.85)	(−1.07)	(−0.93)	(−1.03)	(−0.88)	(−0.91)
Observations	70	68	70	70	70	70	68	70	70	70	70
R^2	0.545	0.470	0.449	0.539	0.448	0.601	0.543	0.608	0.614	0.610	0.608

Table 4
Systemic risk exposure measures forecasting performance.
This table presents results of regressions which use systemic risk measures to forecast future asset returns and stock returns during the 1998 LTCM Crisis and the 2008 Subprime Crisis, specifically surrounding the events of the weeks August 24–28, 1998 and October 6–10, 2008. Asset return data is calculated as the week-over-week change in the market value of assets. CoVaR beta is the institution's Adapted Exposure CoVaR beta, $\beta_t^{j|s}$. This measures the sensitivity of the market value of the institution's assets to shifts in the market value of the assets of the financial system. CoVaR Beta is the standard version of the Exposure CoVaR measure, which uses all available past data. MES measures the average return of the institution during the 5% worst days of market returns, while Granger causality measures the level of interconnectedness between one institution and all others. Both MES and Granger are measured at a quarterly level. Included as controls are one-week lagged asset or stock returns; and one-quarter lagged assets and market beta. Volatility, value-at-risk, and expected shortfall measures are included as controls in unreported results; the inclusion of this set of variables does not alter the results shown below. Fixed Effects which account for whether an institution is a bank, broker, or insurer are also included.
t statistics in parentheses.
* $p<0.10$; ** $p<0.05$; *** $p<0.01$.

	Asset returns						Stock returns			
	LTCM, one qtr		LTCM, six months		Lehman, six months		LTCM, one qtr		Lehman, one qtr	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Adapted CoVaR Beta	−0.0295*		−0.0443***		−0.0809*		−0.00955		−0.0790	
	(−1.91)		(−2.73)		(−1.93)		(−0.53)		(−1.06)	
CoVaR Beta		−0.0663***		−0.0649***		−0.0263		−0.0554		0.0622
		(−3.65)		(−3.53)		(−0.77)		(−1.60)		(1.04)
MES	−0.0736	−0.224	0.813**	0.602*	−0.0738	0.0161	1.080	1.078	0.778***	0.858***
	(−0.26)	(−0.79)	(2.60)	(1.92)	(−0.42)	(0.06)	(1.35)	(1.38)	(3.29)	(3.81)
LVG	0.000825	0.000812*	0.000401	0.000643	0.00138	0.00186*	0.000451	0.000243	−0.00174	−0.000169
	(1.58)	(1.83)	(0.83)	(1.19)	(1.37)	(1.77)	(0.39)	(0.24)	(−0.48)	(−0.05)
Granger	0.000974	−0.000904	−0.000677	−0.000754	−0.000473	−0.000461	−0.00519***	−0.00524***	0.00183	0.00253
	(−1.65)	(−1.66)	(−1.37)	(−1.39)	(−0.90)	(−0.67)	(−2.71)	(−2.70)	(0.71)	(0.95)
Asset Returns	0.00998	0.00550	−0.00970	0.0275	0.0610	−0.0256	−0.0455	−0.0546	0.358***	0.332***
	(0.53)	(0.30)	(−0.32)	(1.03)	(0.50)	(−0.23)	(−0.76)	(−0.99)	(3.90)	(3.41)
ln(Assets)	−0.000727	−0.00228	0.00209	−0.000268	0.00349	0.00442	−0.0157*	−0.0168**	−0.00586	−0.00927
	(−0.24)	(−0.77)	(0.83)	(−0.09)	(0.95)	(1.25)	(−1.98)	(−2.10)	(−0.35)	(−0.56)
Constant	−0.0682	0.0339	−0.0517	−0.00303	−0.111	−0.148*	0.352*	0.386*	0.0973	0.167
	(−0.85)	(0.48)	(−0.88)	(−0.04)	(−1.26)	(−1.76)	(1.78)	(1.98)	(0.25)	(0.44)
Observations	75	75	75	75	70	68	75	75	70	68
R^2	0.534	0.588	0.642	0.620	0.539	0.465	0.288	0.302	0.322	0.322

that LVG may be a measure of stock market undervaluation, since it is measured as market leverage. Thus, it may not be surprising to see overvalued (or low-LVG) firms experiencing a correction in the crisis, leading to a positive sign on LVG. MES is not statistically significant, while LVG is significant at the 1% level. Regression (6) shows that MES lacks statistical significance when included with other variables. LVG retains its positive sign through all regressions. Finally, each regression incorporating the Granger causality measure shows that it is related positively to future returns, and thus suggests that more systemic risk exposure implies higher crisis period returns. Moreover, Granger causality is not statistically different from zero in any regression.

Table 4 presents a second set of results which examines the ability of the measures of systemic risk exposure to forecast the performance of financial institutions during both the LTCM and Lehman Brothers crises, and in terms of both asset and stock returns.[22] I lag all measures one quarter prior to the LTCM crisis, and six months prior to both crisis periods in these regressions. Lagging measures one quarter or more also avoids the possibility of a look-ahead bias. In its measurement, Adapted Exposure CoVaR beta incorporates the interpolated value of book assets over a given quarter. Thus, incorporating systemic risk exposure measurements lagged one quarter prior to the crisis periods mitigates this concern.

Consistent with the results reported in Table 3, regression (1) shows that the one-quarter lagged Adapted Exposure CoVaR beta is statistically significant while MES, LVG, and Granger causality are not during the LTCM crisis period. Adapted Exposure CoVaR beta is statistically significant at the 10% level, and its coefficient implies that higher systemic risk exposure is associated with lower within-crisis returns.[23] Moreover, regression (2) shows that standard CoVaR beta is statistically significant at the 1% level during the 1998 crisis period. Despite its significance in this crisis period, standard CoVaR beta is not statistically significant in the Lehman Brothers crisis. Because a true measure of systemic risk exposure should forecast returns in *all* systemic crises, I interpret the combined results as evidence that standard CoVaR may not a reliable measure of systemic risk exposure while Adapted Exposure CoVaR beta is. Although the power of this evidence for the Adapted Exposure CoVaR beta measure is limited by the fact that I have only two crisis periods with which to test the measures.

The results of regression (1) suggest that a one standard deviation increase in Adapted Exposure CoVaR beta corresponds to a decrease of 0.82% in asset returns during the crisis period. This once again represents an economically large decrease in the performance of financial institutions. The average institution's assets decreased in value by 2.82% during this week, which means that the change in institution performance implied by a one standard deviation shift in Adapted Exposure CoVaR beta is −3.64%, which represents a 29.08% decrease in institution performance below the mean level. In this case, R^2's are notably larger in the regression containing only Adapted Exposure CoVaR beta (47.8%) relative to regressions which contain only MES (31.4%), LVG (40.3%), or Granger causality (31.7%). In contrast, the coefficient on MES is again opposite of what is expected during a crisis period. Finally, the Granger causality measure forecasts in regression (2) that highly connected institutions earn lower returns during the crisis period; however these results are not statistically significant.

Additionally, it would be helpful for a measure to forecast the within-crisis performance of financial institutions when estimated well before a crisis period occurs. I provide estimates similar to the above set of tests. These estimates examine the predictive power of systemic risk exposure measures for institution-level asset returns six months prior to a crisis (I also use nine and twelve-month lagged systemic risk measures. I discuss these results in Section 7). In this case, I estimate the systemic risk measures at a quarterly level, lag them two quarters, and use them to forecast asset value changes during each crisis period. These estimates use the specification of Eq. (5.1). Regressions (3) through (6) of Table 4 display the results of these tests for the LTCM and Lehman Brothers crisis periods. Regressions (3) and (5) show that the six-month lagged Adapted Exposure CoVaR beta forecasts that riskier institutions should experience lower returns during the crisis period. This measure is significant at the 1% level in regression (3), and at the 10% level in regression (5). Meanwhile, the standard CoVaR beta is statistically significant in regression (4) but not in regression (6). This result again underscores the fact that standard CoVaR forecasts returns in 1998 but not 2008. Further, the MES measure by itself forecasts lower returns for risky institutions at the 5% significance level during the LTCM crisis (regressions (3) and (4)), implying a decrease in within-crisis returns of 0.88% for a one standard deviation increase in systemic risk exposure. However, the measure is not statistically significant during the Lehman Brothers crisis (regressions (5) and (6)), and implies that risky financial institutions should expect higher returns. Finally, the Granger causality measure forecasts lower returns for risky institutions; however, the measure is not statistically significant in regressions (3)–(6).

The six-month lagged Adapted Exposure CoVaR beta forecasts that riskier institutions should experience lower returns during both the crisis periods. Using Adapted Exposure CoVaR beta's coefficient in regression (3), a one standard deviation increase in pre-crisis exposure corresponds to a 1.49% decrease in future weekly returns during the LTCM crisis period. Moreover, estimates including Adapted Exposure CoVaR beta yield a higher R^2 than other regressions in the full set of results found in the appendix. These facts suggest that Adapted Exposure CoVaR beta is the superior long-horizon forecaster of within-crisis returns.

One concern regarding the results presented above is the cross-correlation of error terms due to return co-movement during the crisis period. I address this issue in the Online Appendix by re-estimating Table 4 with bootstrapped standard errors. Once again, Adapted Exposure CoVaR beta is statistically significant in all asset return regressions with the exception of regression (4). One quarter prior to the Lehman Brothers crisis, Adapted Exposure CoVaR beta is statistically significant at the 5% level, while two quarters prior to both crisis periods, the measure is statistically significant at the 10% level. Thus, these results assuage concerns regarding the estimation of standard errors in the above results.

Economically, the results shown in Table 4 may be a function of the construction of each variable. The SES-based measures of MES and LVG do not forecast performance over multiple crisis periods. Table 2 shows that MES is highly correlated with the CAPM beta (while Adapted Exposure CoVaR is not correlated with the CAPM beta). This correlation is stronger in the 2008 crisis period than it is during other time periods. MES may be producing results similar to what one would expect from the CAPM beta during the latter period. Accordingly, MES may be estimating *systematic* risk rather than systemic risk. Further, results for the Granger causality variable may be a result of the variable measuring the wrong type of connections. If Granger causality is measuring only connections where two institutions are linked in one direction,

[22] I replicated Table 3 for both crisis periods and for both stock and asset returns. Table 4 summarizes the key results of these tests, as it summarizes regressions (6) and (7) from each individual horse race. Full horse race results are available in the Online Appendix.

[23] Note that Adapted Exposure CoVaR beta is statistically significant at the 1% level when estimating a similar regression when the measure is lagged one week rather than one quarter prior to the crisis.

then it may not be suitable for forecasting within-crisis performance.

5.2. Systemic risk measures forecasting stock returns

Regressions (7) through (10) of Table 4 present estimates which utilize institution stock returns during a crisis period as the dependent variable. This is an important test as the SES and Granger causality measures are designed using stock returns, and it is useful to understand how each measure behaves in terms of forecasting the within-crisis stock performance of institutions.

Regressions (7) and (8) present estimates for the 1998 crisis period. I find that although Adapted Exposure CoVaR beta and MES correctly associate higher risk with lower ex post returns, both coefficients lack statistical significance. These estimates show that for a one standard deviation increase in risk exposure measured by Adapted Exposure CoVaR beta, an institution's within-crisis weekly stock returns decrease by 0.36%. An analogous one standard deviation increase in MES forecasts a 1.06% decrease in weekly stock returns. The Granger causality measure is a statistically significant predictor of stock returns during the 1998 crisis period at the 5% level. Finally, the R^2 for the model which contains only Adapted Exposure CoVaR (20.9%) is slightly lower than models which include only CoVaR (22.3%), MES (22.2%), LVG (21.1%), and Granger causality (26.8%).[24] Regressions (9) and (10) present tests which examine the 2008 crisis period. Adapted Exposure CoVaR beta is not statistically significant in models which include other systemic risk exposure variables. A one standard deviation increase in Adapted Exposure CoVaR beta forecasts a decrease of 1.47% in within-crisis weekly stock returns. Alternatively, MES is statistically significant in regressions (9) and (10). This is not surprising, as the SES measures were developed in part to explain the 2008 crisis period. A one standard deviation increase in MES forecasts a 4.13% decrease in within-crisis weekly stock returns. The R^2's during this period are again relatively close in value, as the difference between the R^2 of regressions with either MES or Adapted Exposure CoVaR is 6.9% (respectively, R^2's are 24.0% and 30.9%). Thus, there is not necessarily a large difference in the ability of MES to explain the variation in stock returns from that of Adapted Exposure CoVaR beta. Finally, the Granger causality measure is not statistically significant in either regression. The measure again forecasts higher returns for riskier institutions.

Because these systemic risk measures were conceived to explain the events of the 2008 crisis, the 1998 crisis period provides an out-of-sample test to discern the effectiveness of the measures. Ideally, a measure of systemic risk exposure should be capable of forecasting the within-crisis performance of financial institutions regardless of the underlying cause of the crisis period. Neither the SES-based measures nor Adapted Exposure CoVaR beta is able to forecast stock returns during the 1998 crisis period despite the ability of MES to do so in the 2008 crisis period. Accordingly, none of these measures is a reliable forecasting tool for stock returns within systemic crises. This result, combined with the results featuring asset returns as a dependent variable, may not be consistent with weak-form market efficiency, which states that past prices should be reflected in the current price. Equity markets may appropriately adjust stock prices, while accounting data is slower to update and adjust asset values.

5.3. Discussion

It is beneficial if a measure of systemic risk exposure forecasts the performance of financial institutions over all crisis periods.[25] If a measure is too heavily based on one crisis period, it will not be a reliable forecasting tool for future crisis periods. This is why the 1998 out-of-sample test is an important indicator of which measure is best suited for this purpose.

The Adapted Exposure CoVaR beta measure fulfills this condition between the two most recent systemic crisis periods in the United States. Meanwhile, the standard CoVaR beta does not reliably forecast the performance of financial institutions during the 2008 crisis. The MES measure does not forecast asset returns during the 2008 crisis, and it does not meet the level of statistical significance of Adapted Exposure CoVaR beta during the 1998 crisis. Further, the Granger causality measure is not a reliable forecasting tool during either crisis period.

The above results, taken together, mean that Adapted Exposure CoVaR beta is the best measure for providing early warning signs of which institutions are most at risk should a crisis occur. Each alternative measure, while having strengths along some dimensions of the proposed criteria, does not perform as well across tests and both crisis periods as Adapted Exposure CoVaR beta.

6. The determinants of adapted exposure CoVaR beta

I now examine what determines the Adapted Exposure CoVaR beta of a financial institution. The benefits of this investigation are twofold. First, the results may provide more confidence that Adapted Exposure CoVaR is measuring the systemic risk exposure of financial institutions. Second, the tests may provide insight as to why some banks have higher exposure to systemic risk relative to their peers. An understanding of what determines systemic risk exposure will also allow financial institutions to modify their levels of systemic risk exposure to better suit their business model and risk tolerance.

To evaluate what determines a financial institution's Adapted Exposure CoVaR beta, I examine the cross-section of all bank holding companies (BHC) immediately prior to each crisis period. I use BHC data for these tests because these financial institutions are required to file quarterly reports with the Federal Reserve. These reports contain more detailed information about the bank's business activities than what is publicly available for other financial institutions. The sample is comprised of 326 BHCs in 1998 and 293 BHCs in 2008. I estimate cross-sectional regressions in which the within-crisis Adapted Exposure CoVaR beta is the dependent variable. The independent variables are estimated in the quarter prior to the crisis, and include a set of crisis-specific variables and a set of control variables. The control variables include institution size, loans to other U.S. financial institutions normalized by total loans, the notional value of equity and foreign exchange futures and forwards contracts normalized by total assets, the institution's market-to-book ratio, and maturity mismatch.[26] Loans to other U.S. financial institutions and derivative positions can be thought of as variables which account for interconnectedness within the financial system (De Bandt and Hartmann, 2000), while maturity mismatch can be considered as a measure of the liquidity of the

[24] These results are found in the Online Appendix. The respective levels of the R^2's are lower than the R^2's of regressions in which the market value of institution assets is the dependent variable. Measures thus do not explain the variation in stock returns as well as they explain the variation in asset returns. However, both Adapted Exposure CoVaR beta and MES are explaining a similar portion of the variation in stock returns during this crisis period.

[25] I also evaluate how systemic risk evolves over time. I do this by examining the ability of each of the measures of systemic risk exposure to forecast the future exposure of financial institutions. If systemic risk exposures are similar over time, then lagged measures should be positively related to current measures. In tests reported in the Section E of the Online Appendix, I use pre-crisis exposure estimates to forecast exposures during the third quarter of 1998 and the fourth quarter of 2008.

[26] Maturity mismatch is calculated as (short term debt − cash)/total liabilities.

financial institution's position. Crisis-specific variables include foreign equity and debt holdings for the 1998 crisis, and securitization activity for the 2008 crisis. Ideally, variables from the 1998 crisis would be included in the 2008 crisis regression and vice versa. However, foreign debt and equity holdings are no longer reported in 2008; and securitization activity was not reported in 1998.

Table 5 presents results associated with both crises. The 1998 crisis period was related to the default of the Russian government and a lack of liquidity in foreign equity markets. Thus, for this crisis, each institution's exposures to foreign equity and foreign debt are included as independent variables in the regressions. Regressions (1)–(2) examine the 1998 crisis. Regression (1) uses all BHCs and regression (2) uses only BHCs above the median asset size. I forecast Adapted Exposure CoVaR in the third quarter of 1998 using financial institution data from the second quarter of 1998.

Regression (3) shows that size is a statistically significant determinant of systemic risk exposure at the 1% level. Economically, the effect of size on systemic risk exposure is large. A one standard deviation increase in bank size is related to a 38.76% increase in Adapted Exposure CoVaR beta after controlling for other bank variables. Moreover, the coefficients on U.S. bank loans are not statistically different from zero. This result suggests that the systemic risk exposure of a financial institution is not affected by the counterparty risk which comes from lending to other financial institutions. While it is surprising that connections between banks do not drive systemic risk exposure, the failure of the Granger causality measure to estimate the within-crisis performance of financial institutions supports this result. Equity futures are negative and not statistically different from zero, while foreign exchange futures are negative and significant at the 5% level. These relations again indicate that interconnectedness may not increase systemic risk exposure. Rather, equity and foreign exchange futures may serve as hedging instruments, which can reduce the riskiness of financial institutions. The foreign debt and foreign equity income variables represent an institution's exposure to foreign securities immediately prior to the crisis period. Foreign equity exposure is positive and statistically significant at the 1% level. Foreign debt has a positive coefficient, but is not statistically different from zero. A one standard deviation shift in foreign equity is related to an increase in systemic risk of 10.85% above the mean level.

Regression (2) repeats the analysis for the 1998 crisis, but examines only banks which have assets above the median level. It is important to consider larger institutions specifically, as they may be considered systemically important. In these tests, size and foreign equity exposure remain statistically significant and have coefficients similar to those in regression (1). Foreign debt becomes statistically significant in this regression at the 5% level, suggesting that these securities may have mattered more to larger financial institutions in terms of their exposure to systemic risk. Overall, these results are consistent with the events of the 1998 crisis period, as firms which had higher exposure, and subsequently poor performance, also had exposure to foreign securities.

Regressions (3) and (4) present results related to the 2008 crisis period. Financial institutions which were active in securitization had exposure to risky asset-backed securities during this period (Acharya et al., 2013). Thus, securitization income is included as an independent variable in this set of regressions. Since securitization is associated with poor performance during this period, financial institutions with higher levels of securitization should have higher levels of systemic risk exposure. Further, I include the trading revenue of a financial institution as institutions with trading operations may have had higher holdings of so-called toxic assets. Regression (3) examines all bank holding companies, and regression (4) examines bank holding companies with assets larger than the median asset size.

Regression (1) shows that the coefficient on size is again statistically significant at the 1% level. Economically, a one standard deviation increase in bank size is related to an increase in systemic risk exposure of 56.33%. Maturity mismatch and market-to-book are both statistically significant predictors of Adapted Exposure CoVaR beta. Increases in both of these variables relate to higher levels of systemic risk exposure. The coefficient on U.S. bank loans is again not statistically different from zero. The coefficients on both equity and foreign exchange futures are again related to lower systemic risk exposures, possibly as a result of their use as hedging instruments. Securitization income is statistically significant at the 1% level, while trading revenue is not statistically significant. A one standard deviation increase in securitization income is related to an increase in systemic risk exposure of 5.91%. In regression (4), which examines larger banks, the coefficient on size and securitization income remain significant at the 1% level.

The above results provide additional evidence that Adapted Exposure CoVaR beta is measuring the systemic risk exposure of financial institutions.[27] In 1998 and 2008, crisis-specific variables are statistically significant predictors of within-crisis Adapted Exposure CoVaR beta. Moreover, this shows that Adapted Exposure CoVaR beta is not crisis-specific, but rather, provides an estimate of systemic risk exposure regardless of the underlying cause of a particular systemic crisis. These tests provide evidence of what types of institutions should be expected to have high exposure to systemic risk. Larger banks have higher exposures to systemic risk. Further, interconnectedness may not play a role in systemic risk exposure, as loans from bank holding companies to other U.S. financial institutions, equity futures, and foreign exchange futures do not forecast future systemic risk exposure. Rather, it may be the case that financial institutions which trade similar assets may be most in danger during a systemic crisis. Finally, I find some evidence that executive compensation does not play a role in determining the systemic risk exposure of a financial institution.[28]

7. Robustness

The above sections show that Adapted Exposure CoVaR beta is a suitable approach to estimating an institution's systemic risk exposure. I run several tests which estimate the extent to which Adapted Exposure CoVaR can be used to estimate the systemic risk exposure of financial institutions. I do not report the results of these tests in the paper, but rather report them in detail in the Online Appendix. In sum, the findings of these tests are as follows. First, I test the limits of forecasting ability for Adapted Exposure CoVaR. I find that during the 1998 crisis, Adapted Exposure CoVaR beta

[27] I also estimate the above regressions using the standard CoVaR beta rather than Adapted Exposure CoVaR beta. Generally, results are similar. Size, Securitization Activity, and Foreign Equity are all statistically significant determinants of CoVaR beta. However, there are some differences. Notably, foreign exchange futures are positive, while foreign debt holdings are negative for the 1998 regressions; and U.S. bank loans are positive, while Maturity Mismatch is not significant in 2008 regressions. These results are available in the Online Appendix.

[28] I also investigate the role executive compensation plays in determining the Adapted Exposure CoVaR beta of a financial institution. The results suggest that the incentives of the managers of large financial institutions do not play a role in determining the systemic risk exposure of financial institutions. Independent variables include the vega and delta of a CEO's outstanding option grants, and the percentage of total outstanding shares that a CEO owns. Vega is the sensitivity of the CEO's portfolio to a 1% increase in the volatility of the underlying stock, while delta is the sensitivity of the CEO's portfolio to a 1% change in the underlying stock price. I also include controls for maturity mismatch, market-to-book ratio, U.S. bank loans, and institution size. In both crises, vega is a positive but not statistically significant predictor of systemic risk exposure. Delta is not statistically significant; however, its sign is negative. Finally, total share percentage is negatively related to systemic risk exposure, but lacks statistical significance. These results are reported in the Online Appendix.

Table 5
Forecasting Adapted Exposure CoVaR beta.
This table presents cross-sectional regressions which feature Adapted Exposure CoVaR beta as the dependent variable. I include the lagged characteristics of financial institutions as dependent variables in the regression. These variables include Size, which is the natural logarithm of the institution's assets; US Bank Loans, which is loans to other domestic banks as a share of total lending; equity and FX futures, which is the institution's equity and foreign exchange futures and forwards, respectively, normalized by total assets; securitization income, defined as securitization income normalized by institution assets; trading revenue, defined as trading revenue normalized by institution assets; and foreign equity and debt, defined as the total institution income from foreign equities or debt normalized by total assets. Due to data constraints, foreign debt and equity are available only for 1998 and securitization income and trading income are available only for 2008. Included as control variables are the institution's maturity mismatch and market-to-book ratio. In all regressions each dependent variable is measured as of the end of the second quarter of 1998, and is used to forecast Adapted Exposure CoVaR beta during the LTCM crisis of the third quarter of 1998. Regressions (1) and (2) examine bank holding companies in the 1998 crisis, while regressions (3) and (4) examine the bank holding companies in the 2008 crisis.
t statistics in parentheses.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

	All BHC 1998 (1)	BHC above median 1998 (2)	All BHC 2008 (3)	BHC above median 2008 (4)
Size	0.0361***	0.0474***	0.0215***	0.0125***
	(7.47)	(5.80)	(7.08)	(2.91)
Foreign equity	0.0101***	0.0136***		
	(4.62)	(4.76)		
Foreign debt	0.00106	0.00334**		
	(0.73)	(2.43)		
US Bank Loans	−2.199	−3.066	2.320	0.628
	(−1.14)	(−1.22)	(1.48)	(0.79)
Maturity mismatch	−0.0337	0.0433	0.0673**	0.0477
	(−0.67)	(0.71)	(1.98)	(1.02)
Market-to-book	0.0279***	0.0337***	0.0211***	0.0248***
	(4.80)	(5.03)	(3.29)	(3.51)
Equity futures	−0.00235*	−0.00221	−4.217***	−2.588*
	(−1.66)	(−1.61)	(−3.84)	(−1.95)
FX futures	−0.00889***	−0.0102***	−0.0000595	0.00808
	(−4.26)	(−4.01)	(−0.01)	(0.74)
Trading revenue			−0.0680	−0.0905
			(−1.21)	(−1.14)
Securitization income			4.213***	5.507***
			(3.80)	(5.70)
Constant	0.0468	−0.0472	−0.269***	−0.182*
	(1.03)	(−0.87)	(−4.52)	(−1.89)
Observations	295	156	279	139
R^2	0.393	0.437	0.354	0.205

is a reliable predictor of the performance of financial institutions at the 5% significance level or better up to one year prior to the onset of the crisis. The measure, however, is a reliable predictor up to two quarters in advance of the 2008 crisis period once other control variables are included in regressions with measures of systemic risk exposure. Second, I further examine the predictability of future exposures. I consider a wider window, using the quarter prior to and following the crisis period for the Russian/LTCM crisis, which corresponds to 1998Q3–1999Q1. The quarters from 2007Q1 to 2008Q4 are considered for the 2008 crisis period. In both cases, as one approaches each crisis period, lagged estimates of Adapted Exposure CoVaR beta gain predictive power. Third, I examine the cumulative return windows over which Adapted Exposure CoVaR beta is an effective predictor of returns during the crisis period. I find that Adapted Exposure CoVaR is capable of forecasting the performance of financial institutions up to a four-week window surrounding the worst portion of the crisis period. Fourth, I estimate whether the $\beta_t^{j|s}$ coefficient fluctuates during a crisis period, because while Adapted Exposure CoVaR estimates the magnitude of the changes in the VaR of an institution due to the institution's exposure to systemic risk, $\beta_t^{j|s}$ measures the actual exposure of the institution to systemic risk. I find that the average $\beta_t^{j|s}$ does not fluctuate in the short term from quarter-to-quarter on a system-wide basis, even though it may vary over the long term. Finally, I attempt to discern whether Adapted Exposure CoVaR beta is exclusively measuring the exposure of financial institutions to systemic risk or if it is also estimating exposure to non-systemic risk and yielding "false positives." I estimate a set of regressions examining its forecasting power during all non-crisis weeks in the 1996–2008 sample period. Accordingly, if the measure is only estimating systemic risk exposure, it should not forecast negative performance during this period. For each regression, Adapted Exposure CoVaR beta is not statistically significant.

8. Conclusion

This paper tests the performance of three leading measures of systemic risk exposure - Exposure CoVaR (Adrian and Brunnermeier, 2016), systemic expected shortfall (SES, Acharya et al., 2016), and Granger causality (Billio et al., 2012) – during two different systemic crisis periods. The primary criterion upon which I evaluate each measure is the ability to forecast the within-crisis performance of financial institutions during the worst weeks of the crises. Further, this paper proposes a modification to the CoVaR estimation methodology. The modified measure, Adapted Exposure CoVaR, incorporates only two year rolling windows of past data in its estimation, while the model of Adrian and Brunnermeier (2016) incorporates all past data. This modification accounts for any change in the systemic risk exposure of an institution over time. I find that among the three measures, the Exposure CoVaR methodology best measures systemic risk exposure. Specifically, the Adapted Exposure CoVaR beta reliably forecasts the performance of financial institutions in different crisis periods, and is a predictor of future risk exposures, where Adapted Exposure CoVaR beta is a coefficient from the CoVaR methodology which relates the change in an institution's assets to a change in the assets of the entire financial system.

Moreover, this paper examines the bounds of the forecasting ability of Adapted Exposure CoVaR beta. I find that Adapted Exposure CoVaR beta can forecast the within-crisis performance of financial institutions up to one year prior to the beginning of a crisis period, and that it can forecast the performance of financial institutions over the five-week cumulative return windows surrounding the worst week of a crisis.

I also examine the benefits of my proposed modification to Exposure CoVaR. I find that Exposure CoVaR provides a reliable forecast of institution performance when it includes only two years of past data in its estimation, but not when it includes all available past data. This shows that systemic risk exposure changes over time within institutions. Thus, estimating Exposure CoVaR using only two years of past data is an essential modification if the measure is to be used to forecast the performance of financial institutions during future crisis periods.

The marginal expected shortfall (MES) and leverage (LVG) measures, along with the Granger causality measure, are not as robust in terms of their use as forecasting variables. These measures lack statistical significance in empirical tests of their forecasting ability. Further, between each crisis period, these variables estimate different relations between systemic risk exposure and the performance of financial institutions. These measures may thus have different meanings during different crisis periods.

Finally, I test the determinants of Adapted Exposure CoVaR beta. During the 1998 crisis, financial institutions with higher exposure to foreign equity had greater systemic risk exposure, while financial institutions with increased levels of securitization income had higher levels of systemic risk exposure during the 2008 crisis. During both crisis periods, larger financial institutions had higher exposure to systemic risk. This provides evidence that Adapted Exposure CoVaR beta measures systemic risk exposure despite the underlying cause of a systemic crisis period. More generally, these results are a first step to understanding what determines systemic risk exposure.

Future research can focus on further investigating the drivers of institution-level systemic risk by incorporating Adapted Exposure CoVaR beta as the primary estimate of institution-level systemic risk exposure. For example, merger activity, securitization activity, executive compensation, and liquidity funding can all be drivers of systemic risk exposure by leading to more interconnectedness in the financial system or by leading institutions to take on greater positions in exotic securities. By exploring these drivers, the reason as to why some systemic risk exposure measures perform differently in different time periods can be examined. Finally, this work may lead to a better understanding of whether institutions modify their exposure to systemic risk over time.

Appendix A. Riskiest institutions during the Lehman Brothers crisis

This table presents the ten banks and insurers with the highest exposure to systemic risk during the 2008 Lehman Brothers crisis. The systemic risk exposure of each institution is reported in terms of the $\beta_t^{j|s}$ coefficient which comes from the Adapted Exposure CoVaR methodology, marginal expected shortfall (MES), and Granger causality. Granger causality connections are measured at the 1% significance level. The exposures reported are estimated as of the week of October 6–10, 2008.

	Bank	CoVaR $\beta_t^{j\|s}$	Bank	*MES*	Bank	Granger
1	Marshall &Ilsley Corp.	0.286	CIT Group	−19.11%	Citigroup	17
2	Capital One Financial Corp.	0.177	Keycorp	−18.67%	KeyCorp	15
3	Northern Trust Corp.	0.176	Citigroup, Inc.	−17.91%	Zions Bancorp	14
4	Bank of New York, Inc.	0.165	Sovereign Bancorp	−17.29%	American Express Co.	14
5	Citigroup, Inc.	0.165	SLM Corp.	−16.48%	Fifth Third Bancorp	11
6	Wells Fargo &Co.	0.160	Marshall &Ilsley Corp.	−15.16%	Suntrust Banks, Inc.	9
7	PNC Financial Services Group, Inc.	0.152	Huntington Bancshares	−14.29%	Marshall &Ilsley Corp.	7
8	American Express Co.	0.137	Bank of America	−14.04%	Bank of America Corp.	7
9	J.P. Morgan Chase &Co.	0.123	Comerica, Inc.	−13.30%	M &T Bank Corp.	7
10	U.S. Bancorp	0.119	Suntrust Banks	−12.98%	Comerica, Inc.	5

	Insurer	CoVaR $\beta_t^{j\|s}$	Insurer	*MES*	Insurer	Granger
1	Ambac Financial Group, Inc.	0.250	Conseco, Inc.	−28.82%	Phoenix Companies, Inc.	23
2	American International Group, Inc.	0.180	Phoenix Companies	−24.97%	Prudential Financial, Inc.	23
3	Chubb Corp.	0.150	Protective Life Corp.	−24.51%	Lincoln National Corp.	21
4	CNA Financial Corp.	0.132	Lincoln National Corp.	−21.92%	CNO Financial Group, Inc.	21
5	Aetna, Inc.	0.131	Prudential Financial	−18.73%	American International Group	14
6	Allstate Corp.	0.125	Unumprovident Corp.	−18.13%	Metlife, Inc.	14
7	MBIA, Inc.	0.123	Principal Financial Group	−17.66%	Principal Financial Group, Inc.	11
8	Unumprovident Corp.	0.098	American International Group, Inc.	−15.97%	Allstate Corp.	11
9	AFLAC Inc.	0.093	Hartford Financial	−15.17%	UNUM Group	8
10	American Financial Group, Inc.	0.086	AFLAC, Inc.	−13.21%	Assurant, Inc.	8

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jfs.2016.04.005.

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