

How to Measure and Regulate Systemic Risk*

Current and past financial crises show that systemic risk emerges when aggregate capitalization of the financial sector is low. The intuition is straightforward. When a financial firm's capital is low, it is difficult for that firm to perform financial services, and, when capital is low in the aggregate, it is not possible for other financial firms to step into the breach. This breakdown in financial intermediation is the reason there are severe consequences for the broader economy.

Motivated from this one economic point, we provide a precise definition of the systemic risk of a financial firm, describe how to measure this risk, and show how this measurement can be implemented using current tools at the regulator's disposal.

Under reasonable assumptions, one can show that the systemic risk of a firm is equal to the

$$\begin{aligned} & \textit{Expected real social costs in a crisis per dollar of capital shortage} \\ & \times \textit{Expected capital shortfall of the firm in a crisis} \end{aligned}$$

The first term above reflects the product of the large bailout costs and real economy welfare losses associated with banking crises times the probability of such crises. The second term deals with the relative contribution of each financial firm to systemic risk through the firm's expected losses in a crisis.

The advantage of the above "formula" for a firm's systemic risk is that it is precise in nature. To measure a financial firm's contribution to systemic risk involves measuring the firm's expected capital shortfall in a crisis. This immediately provides the regulator with a quantifiable measure of the relative importance of a firm's contribution to overall systemic risk. The measure also captures in one fell swoop many of the characteristics considered important for systemic risk such as size, leverage, concentration and interconnectedness, all of which serve to increase the expected capital shortfall in a crisis. But the measure also provides an important addition, most notably the co-movement of the financial firm's assets with the aggregate financial sector in a crisis. The other major advantage of this measure is that it makes it possible to understand systemic risk not just in terms of an individual financial firm but in the broader context of financial subsectors. For example, since the measure is additive, it is just one step to compare the systemic risk of say the regional banking sector versus a large complex bank.

With the above framework, this note describes

- How to set capital requirements in a systemically risky world.
- Four different approaches to measuring a firm's expected capital shortfall in a crisis.
- How to calculate systemic risk charges for financial institutions.
- A methodology for estimating the probability of a financial crisis.

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SUMMARY

Capital Requirements

$$E_{i0} \geq K_i \frac{A_{i0}}{(1 - (1 - K_i)MES_i)}$$

where E_{i0} and A_{i0} are the current equity and assets of firm i respectively, K_i is the hard leverage constraint, and the fraction $\frac{1}{(1 - (1 - K_i)MES_i)}$ can be interpreted as the risk-weight where $MES_i = -E[R_i|crisis]$.

Estimating Expected Capital Shortfall

We want to measure $E(\text{Capital Shortfall}_{\text{Firm } i} | \text{Crisis})$.

This note describes several approaches:

- (i) *regulatory stress tests of financial institutions* that measure their capital losses in adverse scenarios,
- (ii) *statistical-based measures of capital losses* of financial firms extrapolated to crisis periods,
- (iii) pricing of *contingent capital insurance for systemic risk*, that is, an insurance for each firm against itself becoming undercapitalized when the financial sector as a whole becomes undercapitalized, and
- (iv) *market-based discovery of the price of such risk insurance* that financial institutions must purchase partly from the private sector and mostly from the government or the central bank.

How to Calculate Systemic Risk Charges

Tax = Expected losses of the firm's guaranteed debt upon default + Expected systemic costs in a crisis per dollar of capital shortfall \times Expected capital shortfall of the firm if there is a crisis

1. **Government guarantees in the system need to be taken into account**, or in other words, financial firms must pay for the guarantees they receive.
2. The systemic risk also needs to be priced; that is, **financial institutions need to internalize the costs of the negative externality imposed on the system**. We explain below that the expected systemic costs in a crisis can be considered the *time-series* component of these costs (determining the overall magnitude of the costs), and a firm's contribution to these systemic costs can be considered the *cross-sectional* component (determining which firms contribute more to these costs).

Estimating the Probability of a Financial Crisis

An important component of systemic risk is not just expected capital shortfall in a financial crisis, but also the probability of such a crisis. Preliminary work suggests several firm characteristics play an important role: (i) the term structure of volatility, (ii) the average covariance across asset returns of financial firms, (iii) the leverage levels of these firms, and (iv) systemically risky characteristics such as the degree of interconnectedness across firms, the amount of illiquid assets held in the systemically risky parts of the financial sector, and the reliance on systemically risky funding.

Q&A

1. **What is systemic risk?** A definition of systemic risk has been provided by Federal Reserve Governor Daniel Tarullo:

“Financial institutions are systemically important if *the* failure of the firm to meet its obligations to creditors and customers would have significant adverse consequences for the financial system and the broader economy.”

While this definition is useful because it highlights the idea that systemic risk matters only to the extent that there is an impact on the broader economy, we view systemic risk not in terms of a firm’s failure per se but in the context of a firm’s overall contribution to system-wide failure.

Consider the impact of the financial crisis of 2007-2009 on the economy. In the fall and winter of 2008-2009, the worldwide economy and financial markets fell off a cliff. The stock market fell 42% in the U.S. and, on a dollar-adjusted basis, the market dropped 46% in the U.K., 49% in Europe at large, 35% in Japan, and around 50% in the larger Latin American countries. Likewise, global GDP fell by 0.8% (the first contraction in decades), with the decline in advanced economies a sharp 3.2%. Furthermore, international trade fell a whopping 12%. When economists bandy about the word systemic risk, this is what they mean.

2. **How does systemic risk emerge?** Our view is that systemic risk emerges when aggregate capitalization of the financial sector is low. When a financial firm’s capital is low, re-intermediation of financial services is difficult to pull off, and, when capital is low in the aggregate, it is not possible for other financial firms to step into the breach. In the recent crisis, full-blown systemic risk emerged only when, in the early Fall of 08, the GSEs, Lehman, AIG, Merrill Lynch, Washington Mutual, Wachovia, and Citigroup, among others, effectively failed. The result - as we have seen painfully in several crises over past forty years around the world - was loss of intermediation to households and corporations.

To a first approximation, a systemic financial crisis occurs if and only if there is a capital shortfall of the aggregate sector. Of course, the source for an aggregate capital shortfall can take many forms:

- a. Financial firms could all be highly leveraged and face aggregate market exposure. A large shock to the economy could therefore cause large aggregate losses and a capital shortfall.
- b. The financial sector, possibly starting from a weak point, could suffer a capital shortfall if a highly interconnected firm fails and losses reverberate throughout the sector. From our standpoint, the relevant issue is not only that the highly interconnected firm is systemically risky, but that its counterparties are as well by being exposed to that firm.
- c. The financial sector, again possibly starting from a weak point, could suffer a capital shortfall if a large financial firm fails and liquidation of illiquid assets leads to fire sales which pose funding problems for other financial firms which in turn lead to greater liquidations and more funding problems, et cetera. The result is a financial sector death spiral. In our view, the relevant point is not only that this large firm with concentrated holdings is systemically risky, but also other financial firms are as well as long as these firms are exposed to similar risks.
- d. The financial sector, again possibly starting from a weak point, could suffer a capital shortfall if there is a run on a financial firm that runs into trouble and is funded via short-term liabilities. Given the uncertainty about other likewise financial institutions, an aggregate capital shortfall could result because these other likewise institutions might suffer similar runs on their liabilities. The end result is a run on the financial sector. As above, from our standpoint, the relevant matter is not only that the failing firm is systemically risky, but likewise financial firms are as well given that they are also subject to runs even if “solvent”.

What should be clear from the above examples is that systemic risk is really a statement about co-dependence. While the approach to regulation may be different in all of these cases, the bottom line is

that firms which contribute to an aggregate capital shortfall are systemically risky. For example, consider a highly interconnected firm. Reducing the risk of the highly interconnected firm reduces the likelihood of an aggregate capital shortfall because counterparties no longer have the same risky exposure. But to the extent the risk of the interconnected firm remains, the systemic risk is produced not just by that firm failing but by the residual exposures of the rest of the financial sector.

3. ***Which financial firms should be included in this discussion?*** Almost all financial firms have in common the characteristic that they are holders of long-term assets. Through the flow of funds within the economic system, these firms provide financing to real economy firms. These firms are in effect all financial intermediaries, such as banks holding retail, commercial and mortgage loans, insurance companies holding corporate bonds, money market funds buying commercial paper, mutual funds and hedge funds holding equity and other securities, structured investment vehicles pooling loans into asset-backed securities, and so forth. In addition, some financial firms provide additional functions to real economy participants such as payment and clearing, liquidity, insurance against catastrophic risks, etc... The important point is that all firms are potentially important. As we make clear below, the key factor in their systemic risk determination is whether the firm contributes to the aggregate capital shortfall.
4. ***Why is measuring systemic risk so important?*** The current problem with financial regulation is that the regulation seeks to limit each institution's risk in isolation. Unless the external costs of systemic risk are internalized by each financial institution, however, these institutions will have the incentive to take risks that are not borne just by the institution but instead by society as a whole. In other words, individually firm may take actions to prevent their own collapse, but not necessarily the collapse of the system. It is in this sense that the financial institution's risk is a negative externality on the system.

Formal economic theory can be a useful guide to help measure systemic risk. Specifically, in (i) a model of a banking system in which each bank has limited liability and maximizes shareholder value, (ii) the regulator provides some form of a safety net (i.e., guarantees for some creditors such as deposit or too-big-to-fail insurance), and (iii) the economy faces systemic risk (i.e., system-wide costs) in a financial crisis when the banking sector's equity capitalization falls below some fraction of its total assets and that these costs are proportional to the magnitude of this shortfall, the costs of each financial firm are equal to the sum of two components:

$$\text{Costs to society of the financial firm} = \text{Expected losses of the firm's guaranteed debt upon default} + \text{Expected systemic costs in a crisis per dollar of capital shortfall} \times \text{Expected capital shortfall of the firm if there is a crisis}$$

Let us consider these two components in turn.

- *The firm's expected losses upon default:*
That is, the **government guarantees in the system need to be taken into account**, or in other words, financial firms must pay for the guarantees they receive. Because the price of these guarantees will vary across firms because of their specific risk characteristics, each firm will be induced to choose leverage and risk-taking activities more prudently. Currently, in the U.S., the FDIC chooses the level of FDIC premiums on a risk basis though there is skepticism about its success.
- *The firm's contribution to expected losses in the crisis (i.e., the contribution of each firm to aggregate losses above a certain threshold) multiplied by the expected systemic costs when the financial sector becomes undercapitalized:*

Thus, the systemic risk also needs to be priced; that is, **financial institutions need to internalize the costs of the negative externality imposed on the system**. We explain below that the expected systemic costs in a crisis can be considered the *time-series* component of these costs (determining the overall magnitude of the costs), and a firm's contribution to these systemic costs can be considered the *cross-sectional* component (determining which firms contribute more to these costs). Furthermore, and consistent with economic intuition, the

contribution of an individual institution to systemic costs will increase with lower initial capital, riskier asset holdings that contribute to the tail dependence between the institution and the system, institutional and aggregate volatility, and the severity of the externality. Charging the premium causes the financial institution on the margin to hold more initial capital upfront (i.e., to be less levered) and to take less risky positions. That is, facing the “tax,” the financial institutions will organically choose to become less systemic.

5. **What is the interpretation in terms of systemic risk if a financial firm has an expected capital surplus in a crisis?** These firms actually reduce the systemic costs of the financial sector and should be “rewarded”. The intuition is that firms which have plenty of capital, less risky asset holdings or safe funding can still provide financial intermediation services when the aggregate financial sector is weak. Though not all analysts would agree, an argument can be made that the purchase of Bear Stearns by a relatively healthy JP Morgan in March 2008 is one example of a firm covering capital shortfalls elsewhere in the system.
6. **How to set capital requirements in a systemically risky world?** A natural criteria for setting capital requirements would be that a financial firm’s current capital must be sufficient if a financial crisis emerges. The definition of sufficient would mean that the firm would be expected to have enough capital to perform its intermediation functions if the financial sector in aggregate fell short of capital. Using this criteria, Appendix A derives the formal proof of the following result:

$$E_{i0} \geq K_i \frac{A_{i0}}{(1 - (1 - K_i)MES_i)}$$

where E_{i0} and A_{i0} are the current equity and assets of firm i respectively, K_i is the hard leverage

constraint that is consistent with continued intermediation, and the fraction $\frac{1}{(1 - (1 - K_i)MES_i)}$ can be

interpreted as the risk-weight where $MES_i = -E[R_i|crisis]$. In fact, one can interpret this risk-weight as a substitution for the Basel risk-weights. In theory, the risk-weight based on the systemic measure MES incorporates the risk of the underlying assets. The various ways to measure this quantity are discussed on the next several pages. In terms of the underlying intuition, however, firms with systemically risky assets and leverage will have higher MES and must hold higher amounts of capital. For example, if the expected return in a crisis is -100%, then the firm would have to be fully capitalized (i.e., no debt). If the expected return is 0%, then the firm would need to hold just K_i %, say 4%, of capital. Consider the recent financial crisis. The average return of the 25% worst performing bank holding companies was -87% versus -17% for the top performing 25% during the crisis. For $K_i=4\%$, this would translate to a 24.27% capital requirement for the more systemic firms (as measured by MES) and just 4.78% for the less systemic ones.

7. **How do we measure systemic risk?** As described above, economic theory provides a precise measure of systemic risk for a financial firm. It consists of two parts: first, the costs to society of a systemic crisis measured per dollar of capital shortage in entire financial sector, times a second part which is the firm’s anticipated contribution to the capital shortage in that sector.
 - The first part, namely the expected systemic costs involves estimating the probability of a systemic crisis and the external costs of such a crisis. While there is growing evidence on the large bailout costs and real economy welfare losses associated with banking crises (see, for example, Caprio and Klingebiel (1996), Honohan and Klingebiel (2000), Hoggarth, Reis and Saporta (2002), Reinhart and Rogoff (2008), and Borio and Drehmann (2009)), there is little in the literature on estimating the probability of such crises.

An exception is Reinhart and Rogoff (2009), who across a large international data set, document that systemic financial crises are preceded by asset price bubbles, large capital inflows and credit

booms. Our work is more focused on the characteristics of the financial sector and suggests related, yet somewhat different factors, namely the term structure of volatility¹, the average covariance across asset returns of financial firms, the leverage levels of these firms, and systemically risky characteristics such as the degree of interconnectedness across firms, the amount of illiquid assets held in the systemically risky parts of the financial sector, and the reliance on systemically risky funding.

- The second part, formulated as the % contribution of the institution to costs incurred in a financial sector collapse, is the most important component in determining an individual firm's contribution to systemic risk. This component is measurable. The key ingredients are measuring the expected capital shortfall of the firm in a crisis, denoted $E(\text{Capital Shortfall}_{\text{Firm}_i} | \text{Crisis})$.

There are various ways to estimate this value.

- U.S. regulators can implement the above approach using current tools at their disposal. The stress tests employed by regulators in the Spring of 2009 and just this past month can be adjusted in a straightforward manner to allow for estimation of a financial firm's expected capital shortfall.
- And while the stress test methodology can only be implemented on a periodic basis, standard statistical tools can supplement the stress tests to allow for a more continual stream of information regarding the changing nature of financial firms' systemic risk. In work performed here at NYU Stern, at least for the expansive stress tests completed in 2009, we show a close relationship between the stress test outcomes and those implied by statistical measurements using publicly available data.
- An alternative methodology to estimating expected capital shortfalls would be to set an economic price for such shortfalls, i.e., *contingent capital insurance*. These insurance charges would allow the regulator to determine the proportionate share of expected losses contributed by each firm in a crisis, in other words, the relative systemic risk of each firm in the sector.
- One of the issues with estimating expected capital shortfalls in a crisis is that the statistical approach and the contingent claim methodology rely on projecting out the tail estimates of capital shortfall of a firm to an even more extreme event, i.e., when the aggregate sector suffers a shortfall. The assumption is that the cross-sectional pattern amongst financial firms is maintained as events get further in the tail. This is not necessarily the case. In contrast, a market-based solution that uses all available information may be able to uncover these possibilities and then be used to estimate the cross-sectional contribution of each firm to aggregate expected capital shortfall.

8. ***How can the stress test methodology of the government be used to estimate expected capital shortfalls?***

The *Supervisory Capital Assessment Program (SCAP)* initiated in the United States in February 2009 and concluded in May 2009 was originated amidst the credit crisis which had cast into doubt the future solvency of many large and complex financial firms. The idea was to conduct a stress test in order to assess the financial ability of the largest U.S. Bank Holding Companies (BHC) to withstand losses in an even more adverse economic environment. The SCAP focused on the 19 largest financial companies which combined held 2/3 of assets and more than 1/2 of loans in the U.S. banking system, and whose failure was deemed to pose a systemic risk. The goal of the SCAP was to measure the ability of these

¹ The spread between long-term and short-term volatility is of particular importance because a strong case can be made for financial markets being myopic towards long-term risk. While this might be argued on behavioral grounds, an equally plausible explanation arises from financial regulation which focuses on short-term risk, such as value-at-risk. For example, in terms of capital requirements, when short-term volatility is temporarily low, financial firms lever even though long-term risk is much higher. This greatly increases the risk of a financial crisis as the leverage no longer corresponds to the risk of the underlying assets.

financial firms to absorb losses in the case of a severe macroeconomic shock. In particular, the scenarios were two-year-ahead what-if exercises and considered losses across a range of products and activities (such as loans, investments, mortgages and credit card balances), and potential trading losses and counterparty credit losses. The genius of the idea was that regulators could cross-check each firm's estimate of their own losses across these products and therefore get a more precise and unbiased estimate of what the losses should be. Of course, it should be clear that what the regulators were in effect doing were estimating expected capital shortfalls albeit under a given scenario and over an limited two-year time period. This methodology, however, can be extended to estimate systemic risk, i.e., $E(\text{Capital Shortfall}_{\text{Firm } i} | \text{Crisis})$.

- The first, and most important step, is to create a range of economic scenarios or an average scenario that *necessarily* lead to an aggregate capital shortfall. This would be a substantial departure from the recent stress tests performed in the U.S. and those performed in Europe. The question here is a different one than asking whether an adverse economic scenario imperils the system, but instead asks: if the system is at risk, which firm contributes to this risk? Of course, identifying what type of scenario causes an aggregate capital shortfall (and the emergence of systemic risk) may be particularly helpful for understanding the current risk of the financial sector.
- The second step would be to employ the current regulatory stress test methodology to the above economic scenarios. Several adjustments would be needed:
 - i. First, the set of financial firms investigated by these stress tests would have to be greatly expanded beyond the current set of large bank holding companies. This expansion would in theory include insurance companies, hedge funds, possibly additional asset management companies, and other financial companies. This is not only necessary because some of these companies may be important contributors to the aggregate capital shortfall of the financial sector, but also because their interconnections with other firms may provide valuable information about estimated counterparty losses.²
 - ii. Second, because the set of financial firms includes substantial heterogeneity, it is important to assess what constitutes a capital shortfall for each firm, possibly by defining a capital shortfall threshold for each financial subsector. The rule of thumb would be to define a threshold at which the financial firm becomes impaired so that it can no longer perform its usual functions. (See point 3 above.)
 - iii. Third, an important element of a financial crisis is illiquidity, that is, the difficulty in converting assets into cash. Basel III has laid out a framework for banks to go through stress tests scenarios during a liquidity crisis. It seems natural that liquidity shocks would be part of the “doomsday” scenario of systemic risk. The application of such a scenario would be that firms subject to capital withdrawals, whether through wholesale funding of banks, investors in asset management funds, or even (less sticky) policyholders at insurance companies, would have to take a substantial haircut on the portion of its assets that must be sold and are illiquid in light of these withdrawals. Regulators would need to assess both the level of a financial firm's systemically risky

² In order to have any hope of assessing interconnectedness of a financial institution and its pivotal role in a network, detailed exposures to other institutions through derivative contracts and interbank liabilities is a must. This requires legislation that compels reporting, such that all connections are registered in a repository immediately after they are formed or when they are extinguished, along with information on the extent and form of the collateralization and the risk of collateral calls when credit quality deteriorates. These reports could be aggregated by risk and maturity types to obtain an overall map of network connections. What is important from the standpoint of systemic risk assessment is that such reports, and the underlying data, be rich enough to help estimate *potential exposures* to counterparties under

funding and the liquidity of its asset holdings. Cross-checking against likewise institutions would be particularly useful in this regard.

9. ***What is the major problem with performing stress tests?*** The major problem with stress tests is that from a practical point of view the analysis is only periodic in nature and is limited by the applicability of the stress scenarios. Financial firms' risks can change very quickly. This problem suggests that the stress tests need to be augmented with more up-to-date information. It is possible to address this question by conducting a completely analogous estimate of systemic risk, i.e., $E(\text{Capital Shortfall}_{\text{Firm } i} | \text{Crisis})$, using state-of-the-art statistical methodologies based on publicly available data. Specifically, the key ingredients are measuring the expected losses of the firm in a crisis, denoted Marginal Expected Shortfall or MES, and its current leverage status in terms of a potential capital shortfall. In our work, we focus on constructing measures of MES based on public market data and consequently provide a quick and inexpensive approach to determining which firms deserve more careful scrutiny and regulation. MES depends upon the volatility of a firm equity price, its correlation with the market return and the comovement of the tails of the distributions. These in turn are estimated by asymmetric versions of GARCH, DCC and non-parametric tail estimators. The MES is then extrapolated to reflect a financial crisis which takes several months and involves significant market declines. Finally these reductions in equity value will give rise to capital shortages for highly levered firms. The capital shortfall is computed assuming a standard prudential capital buffer. We document considerable success at ranking the systemic risk of financial firms at various stages of the financial crisis, and, as an aside, note that these statistics align quite well with the government's stress tests performed in the Spring of 2009. Of particular importance, the estimates are provided on a timely basis.

Appendix B provides a more detailed description of the procedure, and Appendix C compares our methodology with that of the government stress tests. Appendix D provides an analysis of the statistical measures for U.S. financial firms during the important events of the financial crisis, such as the start of the financial crisis (July 1, 2007), just prior to the collapse of Bear Stearns (March 1, 2008), and the Friday before Lehman Brother's filing for bankruptcy (September 12, 2008). Appendix E extends the analysis globally to large financial firms that belong to the G20 economies for which public data is available.

10. ***Why is the statistical-based methodology more of a supplement to the government's regulatory stress test approach?*** As a general statement, nothing precludes the use of both approaches to measuring systemic risk. As a practical matter, the stress tests provide a more detailed analysis of the potential capital shortfalls of financial firms, so we view the statistical methodology more as a timely way to backup the periodic stress tests. In terms of some of the statistical methodology's limitations:
- The statistical approach uses historical data and thus assumes that statistical patterns that appeared in the past are reflective of future ones. In contrast, because the SCAP is truly an ex ante measure of capital shortfall of these firms, it does not suffer from this assumption as it used forward-looking expectations. Of course, these expectations are subject to biases and may not be the best available given current information.
 - The statistical approach relies on publicly traded data, and, at its core, relies on equity price data. In theory, the market value of equity of these firms takes into account the firm's leverage, the concentration and correlation of its assets within the firm and across the sector, the liquidity of these assets, its interconnectedness to other firms, and whether its liabilities are systemically risky. However, at best, the market value of equity can only incorporate available information to the market that is relevant for pricing equity.
 - The statistical approach relies on projecting out its tail estimates of capital shortfall of a firm to an even more extreme event, i.e., when the aggregate sector suffers a shortfall. The assumption is that the cross-sectional pattern amongst financial firms is maintained as events get further in the tail. It is not clear that this is the case. For example, interconnectedness might rear its problems

only under the most extreme circumstances. If some firms are more interconnected than others, then the estimation methodology will not capture this feature. In contrast, the stress test methodology allows the regulator to take into account not only the regulator's estimate of losses associated with interconnectedness but all the other firm's estimates as well. The calibration across firms may provide a better estimate, not least because some of this information may in fact be privately held.

- The statistical approach relies on publicly available data, so it is limited in scope, not least being applicable to publicly traded companies.

11. *Is there an alternative approach to measuring expected capital shortfalls and systemic risk?* An alternative methodology to estimating expected capital shortfalls would be to set an economic price for such shortfalls. These prices would allow the regulator to determine the proportionate share of expected losses contributed by each firm in a crisis, in other words, the relative systemic risk of each firm in the financial sector.

- Putting aside who receives the insurance payments, suppose we require that each financial firm take out insurance from the regulator against the firm becoming undercapitalized when the financial sector as a whole becomes undercapitalized. The pricing of such an insurance contracts fits into the academic literature on pricing multivariate contingent claims. This literature develops contingent-claim valuation methodologies for cases in which the valuation of claims depends on payoffs that are based on the realizations of multiple stochastic variables. Here, the insurance contract only pays off if the financial institutions' results are extremely poor when the aggregate sector is in distress.
- In contrast to a regulatory approach, a market-based solution that uses all available information may be better able to uncover the price of expected capital shortfalls in a crisis and then be used to estimate the cross-sectional contribution of each firm to aggregate expected capital shortfall. The core idea of a market-based plan to tax systemic risk is that each financial firm would be required to buy private insurance against its own losses in a systemic risk scenario in which the whole financial sector is doing poorly. In the event of a pay off on the insurance, the payment should not go to the firm itself, but to the regulator in charge of managing systemic risk and stabilizing the financial sector. This contingent capital insurance cost, however, is not necessarily equal to the tax. It would be used to determine the proportionate share of each financial firm's contribution to the total systemic risk tax.

This scheme would in theory not only provide incentives for the firm to limit its contributions to systemic risk, but also provide a market-based estimate of the risk (the cost of insurance), and avoid moral hazard (because the firm does not get the insurance pay off). Since the role of the private sector in providing such insurance is primarily for price discovery and the amount of private capital available to provide such systemic insurance likely to be limited, it seems natural that most of the insurance would be purchased from the regulator and the rest from the private sector. Specifically, the solution would be to quasi-privatize the guarantees and systemic costs in the economy through private reinsurance (or a public-private scheme).

12. *Should systemic risk, and therefore regulation, be considered solely from an individual firm's contribution to the aggregate capital shortfall?* It is taken for granted that, ceteris paribus, larger financial firms are proportionately more systemic than smaller firms. But this is not necessarily the right way to think about systemic risk and regulation. While clearly large firms by construction do contribute more towards a capital shortfall, it may well be the case that a collection of smaller firms, or a subsector of the finance industry, contribute more to systemic risk once firm size has been accounted for. For example, the top ten regional banks hold a similar amount of assets to Wells Fargo. If this collection of regional banks were more systemically risky, what would this say about regulation of these regional banks versus Wells Fargo? Are LCFIs like Citigroup, Bank of America or JP Morgan Chase more systemic than a combination of a large bank, and investment bank, an asset management firm and an

insurance company? Is the monoline insurance sector more systemic than the property & casualty one? And the list goes on. This is an important issue for regulators that this framework can address.

APPENDIX A – Capital Requirement

A financial firm has an expected capital shortfall in a financial crisis if its equity value (denote E_i) is expected to fall below a fraction of its assets, i.e., its equity value plus its obligations (denote D_{i0}):

$$E[E_i|crisis] \leq K_i E[A_i|crisis] \equiv K_i (D_{i0} + E[E_i|crisis]) \quad (1)$$

Rearranging the equation, and converting into asset space ($A_{i0} = E_{i0} + D_{i0}$), equation (1) can be rewritten as

$$(1 - K_i)E[E_i|crisis] + K_i E_{i0} \leq K_i A_{i0}$$

Divide both sides by current equity to convert to return space, and define the marginal expected shortfall $MES_i = -E[R_i|crisis]$, we get

$$(1 - (1 - K_i)MES_i) \leq K_i \frac{A_{i0}}{E_{i0}}$$

This gives us the capital requirement

$$E_{i0} \geq K_i \frac{A_{i0}}{(1 - (1 - K_i)MES_i)}$$

where K_i is the hard leverage constraint, say 4%, and the fraction $\frac{1}{(1 - (1 - K_i)MES_i)}$ can be interpreted as the risk-weight.

APPENDIX B – Estimation Procedure

This appendix describes one particular approach to estimating ME\$\$S. In order to estimate the MES, a time series model is formulated that allows volatilities and correlations to change over time which is sensitive to the difference between positive and negative returns.

$$\begin{aligned}
 R_{m,t} &= \sigma_{m,t} \varepsilon_{m,t} \\
 R_{i,t} &= \sigma_{i,t} \left(\rho_t \varepsilon_{m,t} + \sqrt{1 - \rho_t^2} \xi_{i,t} \right) \\
 (\varepsilon_{m,t}, \xi_{i,t}) &\sim F_i
 \end{aligned} \tag{1}$$

In equations (11) there are two volatility processes and one correlation process. The volatility processes are estimated as asymmetric GARCH models of the GJR or Threshold type to allow negative returns to have a special effect on increasing future volatility. The correlation model is a Dynamic Conditional Correlation (DCC) model which incorporates the possibility that correlations rise faster when both assets prices are declining than when they are both increasing. The innovations in this model are required to be uncorrelated but are not required to be independent. Consequently large negative returns on the market may be associated with large negative returns on some financial firms. This type of tail dependence is often addressed with parametric copulas or non-parametric estimation approaches.

From this model, the MES can be defined as

$$\begin{aligned}
 MES_{i,t} &= E_{t-1} \left(-R_{i,t} \mid R_{m,t} < c \right) \\
 &= \sigma_{i,t} \rho_{i,t} E_{t-1} \left(\varepsilon_{m,t} \mid \varepsilon_{m,t} < c / \sigma_{m,t} \right) + \sigma_{i,t} \sqrt{1 - \rho_t^2} E_{t-1} \left(\xi_{i,t} \mid \varepsilon_{m,t} < c / \sigma_{m,t} \right)
 \end{aligned} \tag{2}$$

The first line defines the Marginal Expected Shortfall associated with a market decline of at least c . The second line substitutes the process in equation (11) into the expression for MES to achieve two terms. The first is proportional to the product of the volatility of the firm and its correlation with the broad market. This emphasizes that both the individual firm risk and its correlation with the market are important in systemic risk measurement. The expected shortfall of the market is the same for all firms although it changes over time. Thus it does not affect the rankings. The second term will be zero if the innovations in (11) are independent, hence it measures the importance of tail dependence on computations of MES. We are now using a non-parametric estimate of this tail conditional expectation and smoothing it with a kernel estimator.

To extrapolate this short run MES to the marginal expected shortfall in a crisis, a series of simulations are used. The shocks are drawn from the empirical distribution which is called F_i and then the process follows (11). Some of these simulations have outcomes that are sufficiently bad that they would be classified as a crisis. For these simulations, the mean loss on each firm's equity is computed. Since bad outcomes will be associated with high volatility and correlation, these effects are incorporated in this step. We might call this a long run MES or LRMES. At this point we do not take into account the additional effect of changing leverage but this is planned for the future.

Finally we calculate the expected capital shortfall of each firm if there is a crisis. This is a simple calculation based on the leverage of the firm.

$$SRISK = \min(0, E - k(E + D)) \tag{3}$$

Where E is the market value of equity in crisis, D is the book value of debt and k is a prudential capital requirement which is taken to be 8% in accordance with current regulatory standards. The expected value of equity is simply

$$E = (1 - LRMES) E_0 \quad (4)$$

Where E_0 is today's market value of equity. The contribution to systemic risk then is simply

$$SRISK \%_{i,t} = \frac{SRISK_{i,t}}{\sum_{i=1}^N SRISK_{i,t}} \quad (5)$$

APPENDIX C – Stress Test Analysis

Figure 1: MES Predicts the Stress Tests. The marginal expected shortfall measure (MES), a measure of ex ante systemic risk, plotted against the stress tests' assessed capital shortfall, SCAP/Tier1Comm. MES is an estimate of stock return losses given that the *market return* is below its 5th-percentile, measured for each individual company stock using the period Oct07-Sep08. The sample consists of 18 US financial firms included in the Federal Reserve's stress tests of Spring of 2009.

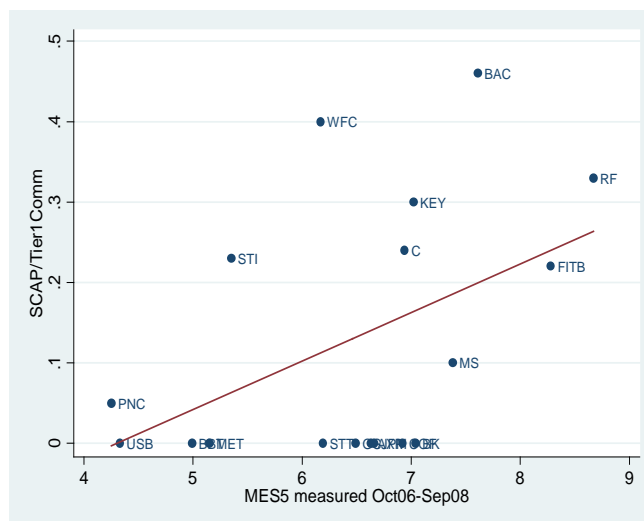


Figure 2: Scatter Plot of Predicted and Government's SCAP Shortfall. The graph depicts a scatter plot of the SCAP capital shortfall versus Shortfall, computed during the April 2008- March 2009 period

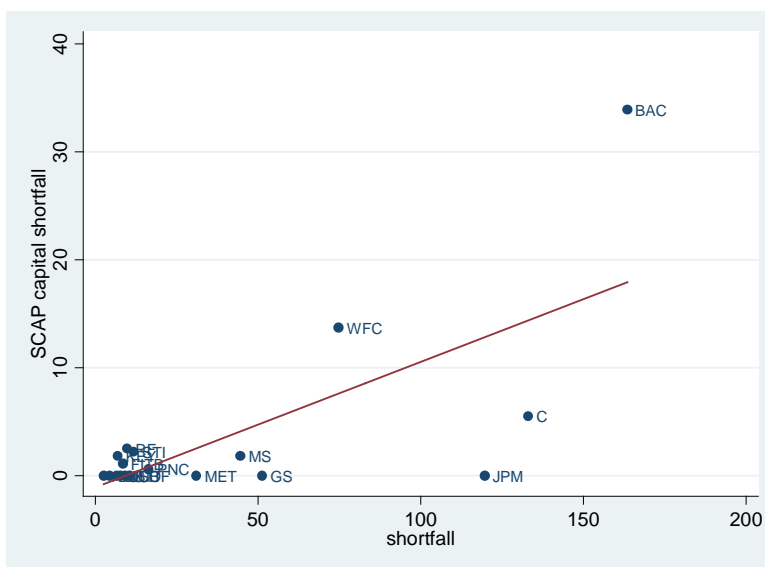


Table 1: Banks Included in the Stress Test, Descriptive Statistics.

Panel A of this table contains the values of SCAP shortfall, Tier1 capital, Tier1 Comm (tangible common equity), all in USD Billion; and, SCAP Shortfall/Tier1, SCAP Shortfall/Tier1 Comm, MES, LVG and Shortfall (in USD million) for the 18 banks who underwent stress testing. MES is the marginal expected shortfall of a stock given that the market return is below its 5th-percentile. Leverage (LVG) is measured as quasi-market value of assets divided by market value of equity, where quasi-market value of assets is book value of assets minus book value of equity + market value of equity. Shortfall is calculated as $\max [0, 0.08 D - 0.92 ME (1 - 6.13 * MES)]$, where D is the book value of debt. SRISK is Shortfall divided by the sum of Shortfall values for all 18 firms. All stock market data are from Datastream and book value of equity is from the merged CRSP-Compustat database. MES was measured for each individual company's stock using the period April 2008 till March 2009 and the S&P 500 as the market portfolio. LVG, ME and D are as of first quarter 2009. **Panel B** shows the average values of the variables separately for samples where SCAP is strictly positive and zero, respectively. **Panel C** shows the correlation between SCAP Shortfall/Tier1, SCAP Shortfall/Tier1 Comm, MES, LVG, and Shortfall.

Panel A									
Bank Name	SCAP	Tier1	Tier1Comm	SCAP/Tier1	SCAP/Tier1Comm	MES	LVG	Shortfall (bln)	SRISK
REGIONS FINANCIAL CORP NEW	2.5	12.1	7.6	20.66%	32.89%	14.8%	44.42	9.76	1.37%
BANK OF AMERICA CORP	33.9	173.2	75	19.57%	45.50%	15.05%	50.38	163.49	22.96%
WELLS FARGO & CO NEW	13.7	86.4	34	15.86%	40.41%	10.57%	20.58	74.74	10.50%
KEYCORP NEW	1.8	11.6	6	15.52%	30.00%	15.44%	24.36	6.82	0.96%
SUNTRUST BANKS INC	2.2	17.6	9.4	12.50%	23.40%	12.91%	39.85	11.79	1.66%
FIFTH THIRD BANCORP	1.1	11.9	4.9	9.24%	22.45%	14.39%	67.16	8.39	1.18%
CITIGROUP INC	5.5	118.8	23	4.63%	24.02%	14.98%	126.7	133.09	18.69%
MORGAN STANLEY DEAN WITTER & CO P N C	1.8	47.2	18	3.81%	10.11%	15.17%	25.39	44.56	6.26%
FINANCIAL SERVICES GRP INC	0.6	24.1	12	2.49%	5.13%	10.55%	21.58	16.39	2.30%
AMERICAN EXPRESS CO	0	10.1	10	0.00%	0.00%	9.75%	7.8	2.59	0.36%
B B & T CORP	0	13.4	7.8	0.00%	0.00%	9.57%	14.78	6.57	0.92%
BANK NEW YORK INC	0	15.4	11	0.00%	0.00%	11.09%	6.46	4.46	0.63%
CAPITAL ONE FINANCIAL CORP	0	16.8	12	0.00%	0.00%	10.52%	33.06	10.49	1.47%
GOLDMAN SACHS GROUP INC	0	55.9	34	0.00%	0.00%	9.97%	18.94	51.34	7.21%
JPMORGAN CHASE & CO	0	136.2	87	0.00%	0.00%	10.45%	20.43	119.71	16.81%
METLIFE INC	0	30.1	28	0.00%	0.00%	10.28%	26.14	31.10	4.37%
STATE STREET CORP	0	14.1	11	0.00%	0.00%	14.79%	10.79	9.12	1.28%
U S BANCORP DEL	0	24.4	12	0.00%	0.00%	8.54%	10.53	7.59	1.07%

Panel B. Average Values

	Where SCAP > 0	Where SCAP = 0
SCAP	7.01	0.00
Tier1	55.88	35.16
Tier1Comm	21.10	23.64
SCAP/Tier1	11.59%	0.00%
SCAP/Tier1Co	25.99%	0.00%
mm		
MES	13.76%	10.55%
LVG	46.71	16.55
Shortfall (bln)	52.11	27.00
SRISK	7.32%	3.79%

Panel C: Correlation Matrix

	SCAP/Tier1	SCAP/Tier1Comm	MES	LVG	Shortfall
SCAP/Tier1	100.00%				
SCAP/Tier1Comm	95.42%	100.00%			
MES	59.48%	61.47%	100.00%		
LVG	31.58%	48.20%	53.70%	100.00%	
Shortfall	37.06%	46.64%	62.01%	31.23%	100.00%

Table 2: OLS Regression and Probit Regression Analyses.

Table 2 summarizes the results of regressing SCAP shortfall on Shortfall (Panel A), and SCAP Shortfall/Tier1 and Shortfall/Tier1Comm, respectively, on MES and LVG (Panel B). Results are presented separately for two periods over which the independent variables are measured: April08-March09 and Oct07-Sep08. For each regression, MES, LVG, and Shortfall are calculated, respectively, during and at the end of the period over which the dependent variable is measured. T-stats and Z-stats are reported in brackets for the regression coefficient estimates in OLS and Probit regressions, respectively. In the Probit regression the dependent variable is converted into a binary variable by only considering non-zero or zero values. The reported R² is then the Pseudo R². ***, ** and * indicate significance at 1, 5 and 10% levels, respectively.

Panel A						
	Dependent Variable is SCAP Shortfall					
	April08-March09		Oct07-Sep08			
	OLS	Probit	OLS			
Intercept	-1.09 (-0.59)	-0.28 (-0.71)	0.98 (0.43)			
Shortfall	0.12*** (3.96)	0.01 (1.08)	0.07* (1.83)			
Adj. R²	46.35%	26.15%	12.18%			
No. Obs	18	18	18			
Panel B						
	Dependent Variable is SCAP Shortfall/Tier1			Dependent Variable is SCAP Shortfall/Tier1Comm		
	April08-March09		Oct07-Sep08	April08-March09		Oct07-Sep08
	OLS	Probit	OLS	OLS	Probit	OLS
Intercept	-16.77* (-1.97)	-6.04** (-2.13)	-13.86 (-1.50)	-30.89* (-1.79)	-6.05** (-2.13)	-27.13 (-1.37)
MES	1.86** (2.43)	0.34 (1.57)	3.24* (2.05)	3.30** (2.13)	0.04 (1.57)	6.57* (1.94)
LVG	-0.001 (-0.02)	0.08 (1.55)	-0.09 (-1.50)	0.12 (0.91)	0.08 (1.55)	-0.17 (-0.34)
Adj. R²	26.76%	54.83%	13.53%	33.19%	54.83%	11.69%
No. Obs	18	18	18	18	18	18

APPENDIX D: Systemic Risk Rankings during the Financial Crisis of 2007-2009

The table ranks the 10 most systemically risky financial firms among the 100 largest financial institutions for three dates ranging from July 1, 2007 through September 12, 2008. The Marginal Expected Shortfall (MES) measures how much the stock of a particular financial company will decline in a day, if the whole market declines by at least 2%. When equity values fall below prudential levels of 8% of assets, the Systemic Risk Contribution, SRISK%, measures the percentage of all capital shortfall that would be experienced by this firm in the event of a crisis. Note that the SRISK% calculations here incorporate existing capital shortfalls from failed institutions.

	July 1, 2007			March 1, 2008			September 12, 2008		
	Risk% (Rank)		MES	Risk% (Rank)		MES	Risk % (Rank)		MES
	SRISK			SRISK			SRISK		MES
Citigroup	14.3	#1	3.27	12.9	#1	4.00	11.6	#1	6.17
Merrill Lynch	13.5	#2	4.28	7.8	#3	5.36	5.7	#5	6.86
Morgan Stanley	11.8	#3	3.25	6.7	#6	3.98	5.2	#7	4.87
JP Morgan Chase	9.8	#4	3.44	8.5	#2	4.30	8.6	#4	5.2
Goldman Sachs	8.8	#5	3.6	5.3	#9	3.14	4.2	#9	3.58
Freddie Mac	8.6	#6	2.35	5.9	#7	4.60	---		---
Lehman Brothers	7.2	#7	3.91	5.0	#9	4.88	4.6	#8	15.07
Fannie Mae	6.7	#8	2.47	7.1	#4	5.88	---		---
Bear Stearns	5.9	#9	4.4	2.9	#12	4.16	---		---
Metlife	3.6	#10	2.57	2.2	#15	2.93	1.9	#12	3.20
Bank of America	0	#44	2.06	6.7	#5	3.60	9.6	#2	6.33
A.I.G.	0	#45	1.51	5.5	#8	4.63	9.6	#3	10.86
Wells Fargo	0	#48	2.38	1.9	#16	4.14	3.0	#10	5.40
Wachovia	0	#51	2.2	4.6	#11	4.64	5.7	#6	9.61

Source: www.systemicriskranking.stern.nyu.edu.