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Forging Best Practices in Risk Management

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Abstract

This paper approaches risk management from three perspectives: firm-level risk measurement, governance and incentives, and systemic concerns. These are three essential dimensions of best practices in risk management; although we discuss each dimension separately, they are interrelated. The paper begins with a brief review of salient changes and unmet challenges in risk measurement in the wake of the financial crisis. It proceeds with a discussion of the interplay between volatility regimes and the potential for risk amplification at a system-wide level through simultaneous risk mitigation at the individual firm level. Quantitative risk measurement cannot be effective without a sound corporate risk culture, so the paper then develops a model of governance that recognizes cognitive biases in managers. The model allows a comparison of the incentive effects of compensation contracts and leads to recommendations for improving risk management through improved contract design. The last section takes a systemic perspective on risk management. Risk managers must recognize important ways in which market dynamics deviate from simple, idealized models of hedging an individual firm's exposures. Firms' collective hedging, funding, and collateral arrangements can channel through the financial system in ways that amplify shocks. Understanding these effects requires an appreciation for the organization of trading operations within firms. The article concludes with a summary and recommendations.

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1. Introduction

The central importance of risk measurement and management techniques to a developed financial system was made abundantly clear during the unprecedented, 2007-09 market turmoil in both the U.S. and Europe. The financial crisis revealed costly gaps in risk management at some of the largest and most complex financial firms. Problem areas included some blind spots in internal risk management, some governance failures in the application of risk management techniques to business decisions, and some surprising examples of how firm-level risk management efforts can interact and amplify to produce bad systemic results. This paper identifies some of the lessons learned and suggests steps toward forging best practices in risk management. This paper takes a three-pronged approach to identifying how risk management practices can be improved, at both the firm level and in the (relatively novel) case of systemic risk management. We are particularly interested in understanding the macroprudential implications of individual firms' behaviors, a new dimension of risk management that motivated creation of the Office of Financial Research in the Dodd-Frank Act.

Traditionally, risk measurement and management occurred within the framework of a single-firm. Although the crisis provides many examples of poor risk management, Paul Glasserman begins Section 2 by listing some of the ways that risk management has changed since the crisis. He then notes that pre-crisis risk analytics often implicitly assumed that the near future would resemble the near past. This, he argues, is a major mistake. Such limited bases for assessing risk caused firms to take large de facto risk positions that seemed relatively safe on the basis of recent economic conditions. Glasserman strongly proposes that adequate risk measurement must incorporate the idea that economic conditions ("regimes") periodically shift. A time of low (or high) price volatility is unlikely to continue forever, and the possible shift to a higher (lower) risk regime must have a substantial influence on ex ante risk assessments. This is a basic, but extremely important, concept for improving the nature of risk measurement at the single-firm level.

Significant advances in analytic capabilities in the years preceding the financial crisis were thought to have improved the accuracy of risk assessment. The value of risk management is realized only to the extent its conclusions are incorporated into a firm's business decisions. Yet senior managements often failed to incorporate risk management views into their business decisions in the run-up to the financial crisis, marginalizing risk management functions both in terms of stature and financial support. Was this behavior an idiosyncratic feature of the euphoric times preceding 2007? Or is it somehow endemic to corporate life?

Clifford Rossi observes in Section 3 that poor corporate governance permitted fundamental breakdowns in risk management before the crisis. But this observation begs an important question: why would senior management implement risk management systems, only to ignore their implications? Rossi addresses this question by viewing risk management outputs through the lens of some well-known behavioral biases, which tend to afflict us all. He argues that at least part of the answer to this question lies in the cognitive biases of senior managers. He applies concepts from behavioral finance to illustrate how cognitive biasesaffect managerial attitudes toward risk. Managers' inclinations to downplay risk in a context of recent profits, for example, lead them to take greater risks, particularly in the presence of weak corporate governance. Cognitive biases gave rise to poor executive compensation structures that failed to incorporate risk, leaving managers with little personal incentive to count risk management information over expected profitability.

Rossi recommends inserting risk management functions more centrally into a financial firm's business decisions. He suggests several specific avenues by which to attain this objective through forces that originate outside the firm. Rating agencies, directors' and officers' insurance writers should evaluate firms' risk-management cultures, and downgrade firms with weak cultures. The FDIC should charge deposit insurance premia that reflect risk cultures. Regulators should also demand more information about changes in risk management personnel and resources. For example, a change in top risk personnel might be made a reportable event, as is the change in a firm's auditor.

A naïve assessment of risk management techniques might indicate that individually well-hedged firms necessarily mean that the system is also well-hedged. Yet the 2007-9 experience strongly suggests that systemic stability differs qualitatively from the stability of individual firms on a stand-alone basis. The Dodd-Frank Act places considerable emphasis on the "macro" stability (risk exposures) of the overall financial system, as opposed to individual firms' exposures. David Mordecai's Section 4 offers a market-wide perspective on risk-management, emphasizing that textbook models of "delta hedging" can be substantially disrupted by non-gaussian price movements and that market power to affect asset prices shifts among participants in response to the evolution of prices and collateral availability demonstrates why techniques, in other words, hedges are not riskless, but generally leave firms exposed to risky contingent obligations. These basis risks need not cancel within a firm. Moreover, different firms' residual risks can coincide with one another, generating crowded trades, illiquidity discounts, and poor risk outcomes at still other firms in the market.

Systemic risk properties can therefore differ quite substantially from those of the individual firms in that system. We know that firms' interactions in asset secondary markets can cause unusual price dynamics (e.g. Brunnermeier and Pedersen (2009)); Mordecai shows that these interactions are likely to reinforce one another much more often than textbook hedging examples would imply.

2. Firm-Level Issues in Risk Measurement (*Paul Glasserman*[1])

This section considers best practices and new challenges from the perspective of a firm's internal risk measurement and the data that supports it. We begin with a brief overview of major trends and developments brought on by the financial crisis. We then focus on a single issue that should be a shared objective of risk management and regulation: How to make risk measurement highly sensitive to risk without producing risk management that amplifies risk. We will argue that this issue is made particularly acute by a historical pattern of volatility regimes. The objective might thus be described succinctly (if somewhat loosely) as *measure procyclically, manage countercyclically.*

The broad problem of risk measurement has strong practical connections with the other aspects of risk management addressed in the other sections of this article – risk governance and systemic risk. Virtually every aspect of risk measurement touches on governance: risk measures create incentives, especially when incorporated into performance measures; the goal of risk measurement should be to inform senior decision-makers; and effective risk management requires a culture responsive to risk measurement, even when the data deliver an unwelcome message. Good data and analysis cannot compensate for poor governance. Anecdotally, at least, there do appear to be genuine shifts in accepted views on risk governance, with the risk function more likely to have independent reporting lines (independent of trading) and greater autonomy than in the past. A continuing challenge is ensuring that risk oversight plays a strategic role and is not reduced to a compliance function.

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[1] I thank Mark Flannery for his helpful comments and suggestions on earlier drafts of this paper, and I thank Tom Piontek for his help with market data.

The interface of firm-focused risk measurement and systemic concerns may be less evident, but the two perspectives interact in important ways. There are at least three channels linking risk as seen from the firm to risk from a system-wide perspective:

- Risk can spread from one firm to another through direct interconnections between firms.
- Financial institutions operate in a common economic and regulatory environment and are thus exposed to common factors. Even if they do not transact directly with each other, their risks may be correlated, and losses can spread from one to another through market prices.
- A risk-mitigating action may be effective when employed by a single firm and yet may amplify risk when employed by many firms simultaneously.

These channels[2] interact, and the boundaries between them are not sharp, but they are nevertheless useful in thinking about why a firm should pay attention to systemic risk and why a macroprudential regulator needs to know how firms measure and manage risk internally. We will focus on the last of these channels after reviewing changes to risk measurement in Section 2.2 and discussing volatility regimes in Section 2.3.

2.1. What Has Changed

Before focusing on a single theme, we highlight some areas of risk management that have been most affected by the financial crisis and areas that present unmet challenges.

Taking a longer-term perspective on risk: Not long ago, the Great Depression seemed largely irrelevant to modern risk management; today, it helps inform stress scenarios.[3] We will argue in subsequent sections for the importance of taking a long-term view, both in looking at history and looking forward. A crucial feature of the historical record that may not be evident from just 2-3 years of history is a pattern of volatility regimes with a profound impact on risk measurement.

Radically heightened attention to counterparty risk: The financial crisis has accelerated a trend that started earlier[4] to substantially improve the management of counterparty risk, and it

[2] For examples, overviews, and additional background, see Upper and Worms (2004); Shleifer and Vishny (2011); Brunnermeier and Pedersen (2009).
[3] See, for example, the recalibration of "AAA" in Adelson (2009).
[4] See, for example, Counterparty Risk Management Policy Group (2005).

has brought the notion of firms too-interconnected-to-fail to macroprudential concerns. Important causes and consequences of these developments include the following:

- The collapse of AIG and several monoline insurers were stunning reminders that high credit ratings cannot substitute for due diligence and careful monitoring of counterparties; the failures of Bear Stearns and Lehman Brothers brought a sharp reassessment of counterparty risk in prime brokerage and the over-the-counter derivatives business.
- The Libor-OIS spread climbed dramatically in August 2007 and again in September 2008 (see Figure 1), and it shows no sign of fully returning to its small and stable pre-crisis level. The spread is widely viewed as a market measure of inter-bank counterparty risk because Libor presupposes an exchange of principal whereas the OIS rate entails only an exchange of interest payments. We see similar decoupling between 6-month Libor and 3-month Libor, reflecting concerns over banks' ability to roll their debt, and the same pattern holds between Euribor and Eonia rates.[5]
- The use of collateral in derivatives transactions has climbed steadily. According to ISDA surveys[6], 80% of OTC derivative contracts between major dealers were collateralized in 2010, compared with 55% in 2000.
- Portfolio compression services, which provide market participants opportunities for multilateral netting of OTC derivatives, report the elimination of $30.2 trillion in notional outstanding of credit default swaps in 2008 and $14.5 trillion in 2009, and compression of both interest rate swaps and credit default swaps continues on a very large scale. Compression imposes some costs on participants, so the level of activity reflects concerns over the operational challenge of monitoring counterparty risk.
- The Dodd-Frank Act mandates moving most derivatives from OTC trading to central clearing to bring greater transparency to counterparty exposures and to try to reduce the build-up of counterparty risk.

[5] The stock market crash of 1987 left a permanent mark in the equity derivatives market through the emergence of the implied volatility "smile," reflecting a new appreciation of tail risk. The decoupling of interest rates may similarly be a lasting legacy of 2007-2008 reflecting a permanent repricing of counterparty risk.

[6] International Swaps and Derivatives Association (2011), *ISDA Margin Survey 2011;* International Swaps and Derivatives Association (2000), *ISDA Collateral Survey 2000.*

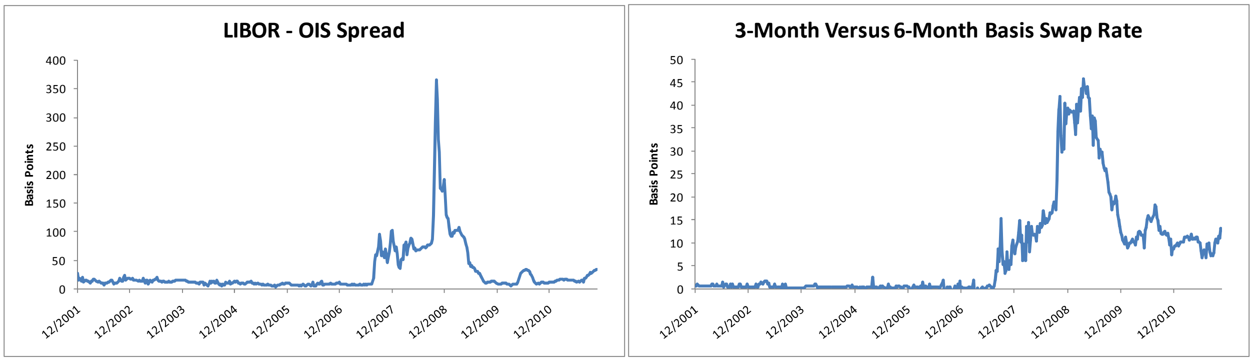

Figure 1: The left panel shows the difference between 3-month USD Libor and the OIS swap rate. The right panel shows the swap rate for a 1-year swap of 3-month Libor versus 6-month Libor.

A new focus on funding liquidity: The lead-up to the financial crisis pushed the limits of liquidity mismatches, with special investment vehicles using very short-term funding to buy illiquid and long-dated asset-backed securities, the major investment banks relying on billions of dollars of overnight repo funding, and prime brokers and insurers using securities lending to fund investments in risky assets. The flight of short-term funding was a major factor in the failures and near-failures of 2008. The aftermath of the crisis has brought tighter controls to the repo market, new rules for money market funds that constrain their role as a source of short-term funding, and proposed liquidity buffers for banks as part of Basel III. A tighter integration between funding and investment is evident in the OTC derivatives markets, where it has become necessary and standard practice to quote different prices based on different funding rates depending on funding and collateral arrangements.

The integration of market and credit risk: This has long been a challenge for risk management, and it underpins counterparty risk. Industry practice and new regulations[7] have pressed the need for integration through the institutionalization of credit value adjustment (CVA) in the derivatives business. Calculating a CVA on a swaps portfolio, for example, requires joint modeling of a counterparty's default risk together with the market factors driving swap values in order to capture "wrong-way risk" – the risk that the counterparty's propensity to default increases together with the value of trades with that counterparty. The challenge in capturing these effects is partly a data constraint – limited liquidity in credit default swap spreads to measure credit risk, for example – but it is primarily a modeling challenge.

[7] See, Basel Committee on Banking Supervision (June 2011).

Reduced reliance on credit ratings: The shortcomings of credit ratings, particularly for structured products, have been widely discussed as an important contributing factor in the financial crisis.[8] The crisis has left skepticism about reliance on credit ratings, and the Dodd-Frank Act bars the use of credit ratings from regulatory requirements. These developments shift much more responsibility to a wide range of market participants to undertake greater due diligence in their credit analysis; it remains to be seen how the need for this capability will be met and how further regulatory changes will affect the role of credit rating agencies. Basel III capital requirements continue to make reference to credit ratings.

New levels of sovereign risk: Until recently, sovereign risk was almost entirely limited to emerging markets. A U.S. downgrade and a crisis in Europe that intertwines bank and government debts across borders have changed that. At the same time, credit default swaps – essential tools in the measurement and management of sovereign risk – have lost much of their effectiveness through policy actions taken to prevent outright default. Indeed, sovereign risk poses a special challenge for the quantitative tools of risk measurement, given its intrinsic dependence on political decisions.

A shift from probability to uncertainty: The general trend in the development of modern risk measurement has been toward increasing model sophistication in estimating probabilities of losses and rare events. At the same time, the financial crisis has brought a renewed appreciation for the importance of imagining the unthinkable and developing stress scenarios, thus bringing a greater role for uncertainty that cannot be quantified probabilistically into risk management. The crafting of meaningful stress scenarios remains as much art as science and merits further research.

Managing through regulatory uncertainty: The Dodd-Frank Act introduced a broad range of regulatory changes, but the crafting and implementation of rules will continue for some time. New capital and liquidity requirements under Basel III will be phased in over time, and this is likely to prolong debate over final rules. To be sure, regulatory changes are always possible, but the near-term environment will be characterized by a higher than usual level of regulatory uncertainty.

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[8] For example, "the failures of credit rating agencies were essential cogs in the wheel of financial destruction," *The Financial Crisis Inquiry Report,* Government Printing Office, Washington, D.C., p.xxv.

2.2. A Historical Perspective: Volatility Regimes

We will now focus on a particular dimension of risk measurement – the impact of volatility regimes – because of its importance in connecting firm-level risk and system-wide risk.

2.2.1. A Look Back Through VaR

It is convenient to mark the beginning of modern risk management at the widespread adoption of value-at-risk (VaR), following the 1992 publication of J.P. Morgan's *RiskMetrics Technical Document* defining the concept. VaR quantifies the risk in a portfolio through a percentile – often the 99^{th} percentile of the loss distribution over a one-day or two-week horizon.

The shortcomings of VaR, reflected in its misinterpretation and in the assumptions underlying its calculation, have been widely discussed from the start. So it is worth pausing to consider the things VaR gets right. First, it requires tracking the market risk factors to which a portfolio is exposed and maintaining historical data on these market risk factors. More fundamentally, it requires taking stock of every position in a portfolio; and calculating a firm-wide VaR requires aggregating all positions across the firm. The development of the data infrastructure required to achieve this aggregation across diverse units, and the discipline it imposes on position monitoring may be the greatest benefits of creating a VaR system. The seemingly simple task of "knowing what you hold" continues to challenge even sophisticated financial institutions, as evidenced by the continuing uncertainty surrounding ownership of countless mortgages, gaps in trade confirmation famously exploited by traders at Société Générale and UBS, and the apparent disappearance of funds from MF Global. Anecdotal evidence suggests that firms that had an integrated view of their exposures across the institution fared better through the financial crisis than those that did not. Greater clarity on exposure to Lehman by its largest counterparties might well have led to smoother unwinding of the firm the weekend of September 13-14, 2008.

A useful model, even a flawed one, helps organize thinking around a problem. A VaR calculation forces us to think about what exactly we are trying to measure. To ground our discussion, consider the patterns in Figures 2 and 3, reproduced from the 2006 and 2007 annual reports of Bank of America. Like most major financial institutions, the bank reports using a historical simulation approach to VaR. In each figure, the upper line shows daily trading-related revenue, and the lower line shows the bank's one-day VaR at 99% confidence. One might expect the upper line to cross the lower line roughly every hundred days or 2-3 times per year. Indeed, this expectation is embodied in rules[9] for backtesting VaR that penalize a bank based on the number of such exceptions; observing exceptions is also useful in calibrating a VaR model. But throughout 2006, the lines in Figure 2 never come close to crossing.[10] The figure might suggest that the VaR calculation is far too conservative.

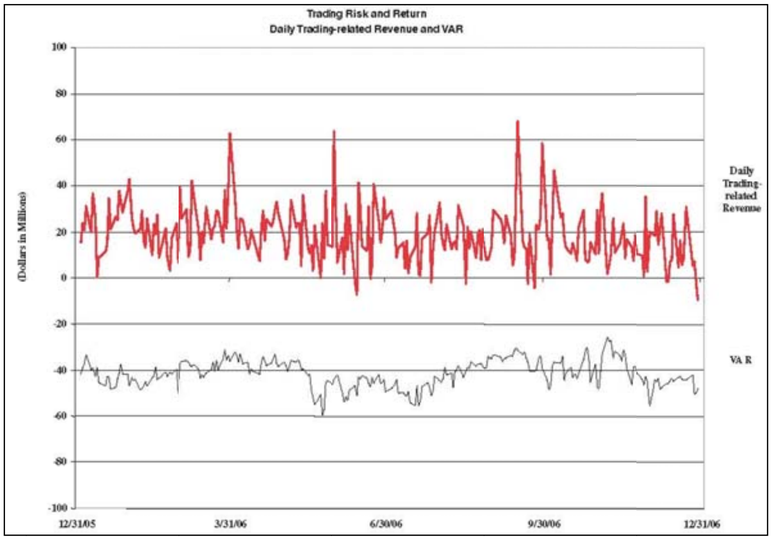

Figure 2: Performance of Bank of America's Daily VaR in 2006

Figure 3, showing results for 2007, tells a different story. The first six months are similar to 2006, but in the second half of the year the bank reported a total of 14 days on which losses exceeded the VaR, compared to an expected value of 1-2 days. This is not a “black swan” event – a rare extreme occurrence drawn from the tail of a distribution. Given the onset of a cluster of extreme moves, the pattern might better be described as a “black sky” event.

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[9] *Federal Register* (1996)

[10] The upper line may include trading-related fees that increase revenues without affecting VaR, but given the magnitude of the gap, it seems unlikely that it can be fully explained by fee income.

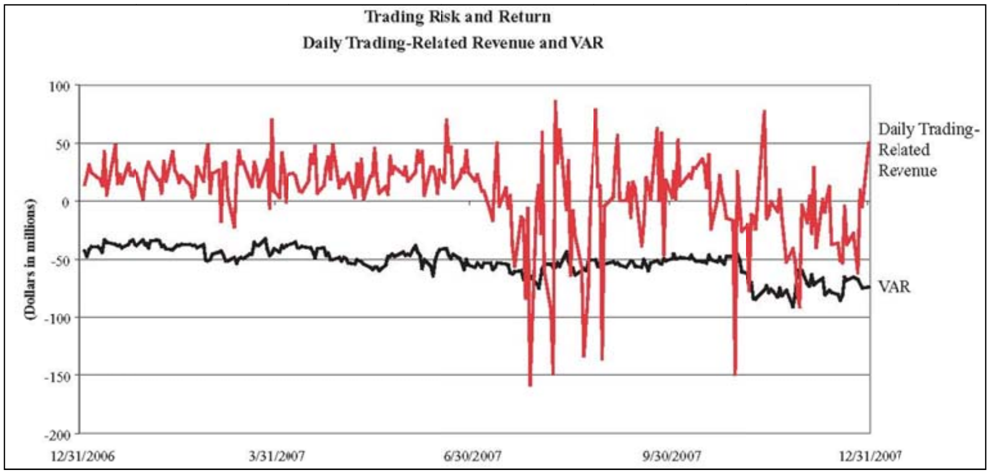

Figure 3: Performance of Bank of America's Daily VaR in 2007

The figures indicate that there is no simple answer to the question of whether the VaR estimates are too conservative or not conservative enough – they are both. More fundamentally, the figures force a question about what loss distribution we are trying to summarize. Is it a conditional distribution, conditional on current market conditions? Such an estimate would respond more quickly than what we observe in Figure 3. Drawing on the previous 2-3 years of market data through a historical simulation comes closer to approximating an unconditional distribution. We will argue in the next section that this distinction is important because of the pattern of volatility regimes in market data and that both types of estimates need to be incorporated into risk measurement.

2.2.2. Volatility Regimes

If there is any universal law of market data, it is that market returns exhibit high *kurtosis*: the distribution of returns of virtually every market variable shows a higher peak and heavier tails than would be predicted by a normal (Gaussian) distribution. This fundamental feature of market data has been observed since at least the work of Mandelbrot (1963) and Fama (1963), and it remains at least as prevalent today.

However, this crucial feature of the marginal distribution of market returns does not tell the full story. A good candidate for a second universal law of market data is the intermittency or burstiness of volatility. Indeed, heavy tails alone cannot explain the pattern in Figures 2 and 3, a pattern repeated in the exceptions of many other financial institutions during the same period. The pattern is best understood through a shift in regime, specifically a shift in volatility regime.

To help illustrate this point, Figure 4 plots the level of the VIX volatility index, at a weekly frequency, from 1990 through October, 2011, on a logarithmic scale. For purposes of discussion, we use the VIX as a simple proxy for the overall level of market volatility. The figure strongly suggests a volatility cycle. Casual observation suggests that the time interval displayed can be usefully divided into two periods of low volatility and two periods of high volatility, each lasting 4-6 years. In this partition, a transition from a low volatility regime to a high volatility regime occurs sometime in the second half of 2007, consistent with the pattern in Figure 3.

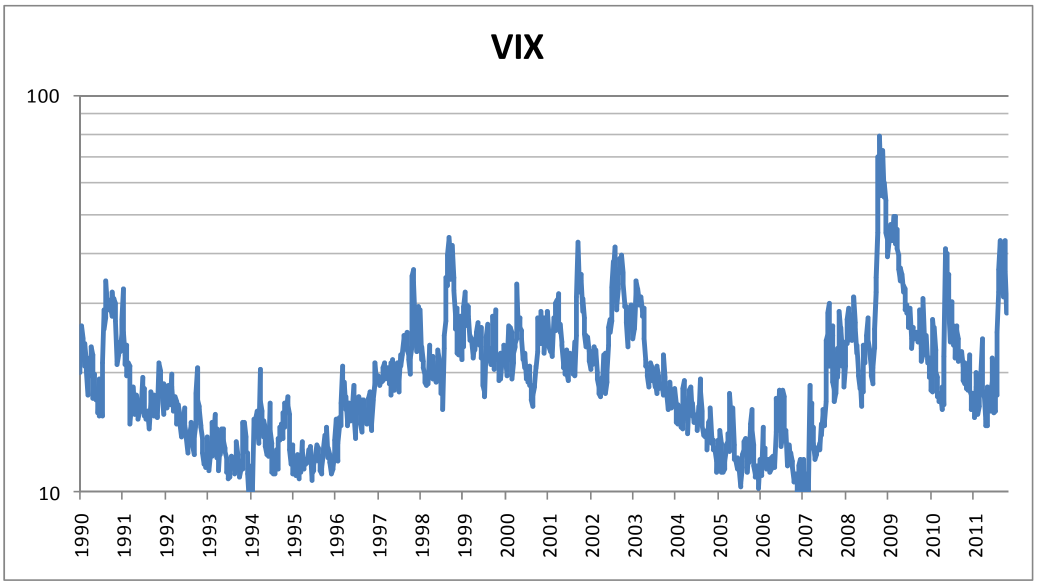

Figure 4: The VIX volatility index, 1990-2011

Figure 5 shows daily returns of the S&P 500 over the same period and thus illustrates realized (as opposed to option-implied) volatility. The figure shows a familiar pattern of alternating periods of relative calm and volatility. This pattern goes a long way toward explaining kurtosis, in the following sense: The combined data from the beginning of 1991 through October 2011 has a kurtosis of 11.7; if we break the time series at the end of February 1997, April 2003, January 2008, and March 2009, the kurtosis within each of the five intervals is never more than 5.8. This is still higher than the value of 3 that would be obtained from a normal distribution, but it indicates that much of the kurtosis that we see in the historical record results from mixing periods of low and high volatility.

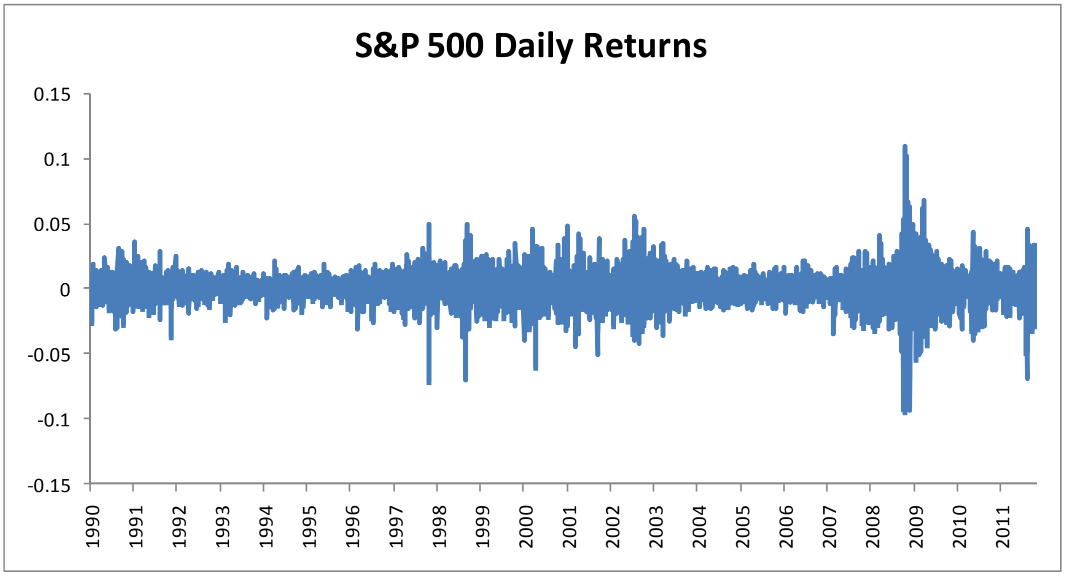

Figure 5: Daily returns of the S&P 500 index, 1990-2011

This pattern is by no means limited to equity markets. The left panel of Figure 6 plots the MOVE index, a measure of interest rate volatility, and the J.P Morgan Global FX Vol Index, a measure of exchange rate volatility, both of which exhibit regimes. The right panel plots the spread between the interest rate for Baa corporate credits (as reported by the Federal Reserve) and the 5-year Treasury yield, and this shows a similar pattern. The patterns in Figures 4-6 divide the time period into similar, if not identical, regimes.

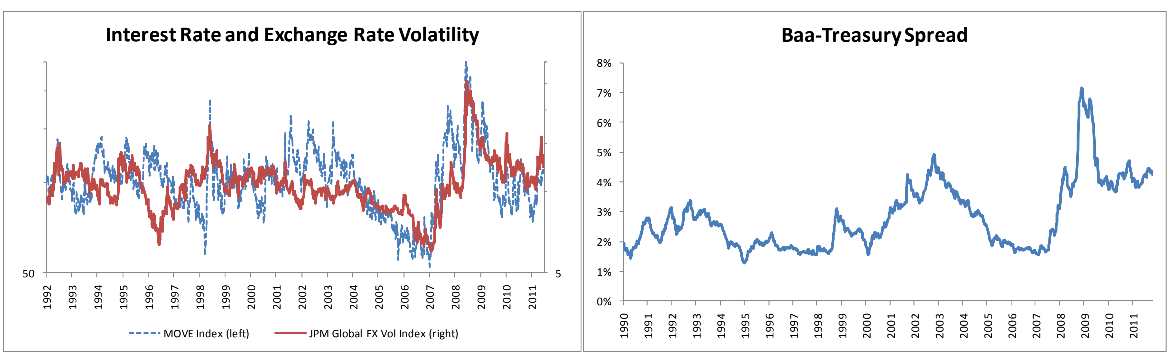

Figure 6: Apparent regimes in interest rate volatility, exchange rate volatility, and a credit spread. The volatility indices on the left are shown on a logarithmic scale.

Now we revisit the VaR results in Figures 2 and 3, placing ourselves somewhere in the first half of 2007. If we look back 2-3 years (a window often used in estimating risk parameters) in any of Figures 4-6, we see only calm. Looking back in Figure 4, we see the VIX hovering in the teens. We could look back all the way to 2003 without seeing the VIX spend significant time above 20. A VaR calculation calibrated to this time period would reflect an expectation that these low levels of volatility would continue. One could reasonably argue that the subsequent climb of the VIX above 80 could not have been anticipated. However, the return to some elevated volatility plateau certainly might have been anticipated as a plausible scenario – not by looking back 2-4 years, but by looking back 20 or so years.

A regime-switching model formalizes this idea by positing underlying states or regimes.[11] Within each regime, model parameters are fixed, but the parameters in different regimes can be very different. The model specifies a mechanism (in the simplest case, a coin toss independent of everything else) for switching from one regime to another. A limitation of this approach is that a very long historical record is needed for precise estimation – it is difficult to glean information about transitions if the record includes only 4-5 regime switches. An alternative is a GARCH model, which also captures persistence in volatility. Our objective here is not to advocate a specific econometric approach but rather to highlight the importance of a volatility regime mindset both for firm-specific risk management and for the systemic consequences we discuss next.

2.3. Systemic Implications: Micro Meets Macro

Having reviewed some evidence of volatility regimes in market data, we now consider the implications of this pattern. We will argue that this pattern presents more than just an econometric challenge for risk measurement – it is an essential feature of firm-specific risk management and the systemic implications of the combined effects of multiple firms. We will argue that risk can be amplified when multiple firms attempt to take the same risk-mitigating steps; if many firms are prompted to take similar actions simultaneously by a change in volatility regime, the effect becomes particularly acute.

We noted earlier that there are several points of contact between firm-specific risk management and a systemic view of risk. The most immediate is that the regimes suggested by Figure 4, like the closely related business cycle, affect all firms simultaneously. This effect begins as systematic risk – aggregate market risk that cannot be diversified away; it becomes systemic when it is amplified by the operation of the financial system.[12]

[11] For an early reference, see Hamilton (1989). For a recent review, see Ang and Timmermann (2011). For a specific application to VaR, see Kawata and Kijima (2007).

[12] A fuller discussion of the systematic-systemic contrast is given in Section 3.

Regulations that are "procyclical" are one source of amplification. A procyclical regulation is one that tightens constraints on credit provision during an economic downturn thus contributing to a worsening downturn. The potential procyclicality of risk-based regulations has long been observed[13] and has garnered special attention in analyses of the financial crisis.[14]

Longbrake and Rossi (2011) examine the following sources of procyclicality: Loan loss reserve accounting rules, which lead to declining loss reserves in good times and growing loss reserves as the economy sours; capital requirements that similarly lead banks to hold more capital as credit quality deteriorates; deposit insurance fees, which have tended to be lower before financial crises and increased during and after crises[15]; and fair value accounting rules, which may contribute to a downward spiral[16] as financial distress leads to forced sales, pushing down prices, triggering write-downs and exacerbating distress. Longbrake and Rossi (2011) also examine new liquidity requirements proposed under Basel III as potentially procyclical. In each case, procyclicality can be reduced by making the rules less regime-sensitive: less sensitive to losses, falling prices and increased risk. We return to this point in Section 2.4.

Risk-mitigation strategies employed by firms or individual investors can have similar amplification and feedback effects:

- A classic example is a bank run: whereas it may be prudent for a single depositor to manage risk by withdrawing funds from a dicey bank, this strategy will push an uninsured bank into failure if followed simultaneously by enough depositors.
- The stock market crash of 1987 has been attributed[17], in part, to the use of portfolio insurance strategies that trigger selling in a declining market, a strategy that may work when used by a small number of investors but that leads to a downward cascade if applied widely.
- More recently, the "quant crisis" of August 2007 appears to have resulted from a near-simultaneous deleveraging by many hedge funds with similar investments (Khandani and Lo 2007). Each fund might have counted on the ability to sell off assets as a way to manage risk without anticipating the effect of multiple funds doing so simultaneously.

[13] See, e.g., Blum and Hellwig (1995).
[14] See, e.g., Repullo, Saurina, and Trucharte (2010).
[15] See also Pennacchi (2005).
[16] In principle, fair value corrects for temporary illiquidity effects, but this is difficult to implement in practice.
[17] See, e.g., Brady (1988).

- In the same spirit but in a different setting, it was collateral calls that pushed AIG over the edge. Each counterparty may have taken comfort in knowing that it could demand collateral from AIG in the event of a downgrade. But draining cash through collateral calls led to further downgrades and yet more collateral calls in a cycle that would have led to large losses to the counterparties but for the injection of government funds.
- More recently, concerns have been raised[18] about potential amplification through hedging of counterparty risk when credit default swaps are used both to measure the risk and to mitigate it: a widening CDS spread signals increased risk, triggering more protection buying, which leads to further spread widening.

In each of these examples, an action that would reduce risk for a single agent amplifies risk when undertaken simultaneously by multiple agents.

Adrian and Shin (2009) document an apparent strategy by (pre-crisis) investment banks to vary the size of their balance sheets as if to target a level of VaR, selling assets as volatility increases. It is interesting to revisit Figure 4 with this in mind. During an extended period of low and declining volatility (from around 2003), this would lead to ballooning balance sheets. The spike in volatility in 2007 then creates a rush to the exit as firms try to lower their risk. By pushing prices lower quickly, the sell-off leads to a further increase in volatility. We thus have a dangerous combination of two ingredients: a widespread strategy to manage an increase in volatility through deleveraging, combined with a historical pattern of volatility regimes. An event that triggers an increase in volatility has a cascading effect as firms react. Indeed, the impact runs in both directions, as Adrian and Shin (2009) show that changes in the repo funding by broker-dealers forecast changes in financial market risk as measured by the VIX.

2.4. Implications for Risk Management Best Practices

We have suggested that volatility regimes are an essential feature of market data and observed that this feature can trigger (and may be triggered by) an amplification in risk precisely through practices meant to reduce risk. What, then, can be done to address this phenomenon? We consider this question first from the perspective of an individual firm and then from a systemic perspective. There are no simple solutions – if there were, they would have been adopted already – but we can nevertheless highlight priorities for further work.

[18] See, e.g., Carver (2011).

Take a longer look back: As we have already noted, and as Figures 2-6 make clear, looking at 2-3 years of past data gives an incomplete picture of financial risk. Some important features emerge only over a time scale of 20 or more years.

Take a longer look forward: The VaR horizon for market risk under Basel rules is two weeks, and portfolio composition is assumed to remain fixed over this horizon to reflect potential illiquidity in the market. Figures 4-6 reinforce the importance of taking a longer-term view. This clearly presents many practical challenges. The Incremental Risk Charge included in the so-called Basel 2.5 rules offers an interesting approach: it requires a VaR calculation over a 1-year horizon; and rather than hold a portfolio fixed, it assumes rebalancing to a target level of risk, with the rebalancing frequency tied to asset liquidity. This is a relevant framework for any attempt to quantify portfolio risk over a relatively long horizon.

Stress test through regime changes: We noted earlier a trend toward greater use of stress scenarios and less reliance on quantifiable probabilities. An awareness of volatility regimes points to important features that should be included in stress tests: not just isolated extreme events, but extended periods of increased volatility across multiple markets.

Remember the categorical imperative: Risk managers need to consider the effectiveness of a risk-mitigating action when the same action is undertaken simultaneously by many other firms.

From a systemic or supervisory perspective, volatility regimes reinforce a continuing concern over the procyclicality of regulation. Indeed, much has been written about procyclicality in regulation. In addressing procyclicality that results from firms' own risk management procedures, "best practices" face conflicting objectives. On one hand, they should encourage firms to invest in developing precise – and thus sensitive – measures of risk; on the other hand, it is this very sensitivity that amplifies risk if it triggers widespread similar responses. The challenge, then, lies in achieving the smoothing effect of countercyclical measures without numbing sensitivity to risk.

As an example of numbing, deposit insurance solves the problem of bank runs by making depositors indifferent to bank risk and removing any incentive to monitor risk; this is a logical solution for individuals but not the behavior one would want from financial institutions. In a less extreme example, Repullo et al. (2010) observe that using (unconditional) through-the-cycle default probabilities, rather than (conditional) point-in-time estimates reduces the procyclicality of capital; it does so by reducing risk sensitivity. An alternative they discuss, based on a GDP multiplier, is countercyclical without being less risk-sensitive; the moving-average proposal of Gordy and Howells (2006) has a similar effect.

To achieve both precise risk measurement and effective buffering against the amplifying effects of responses to risk, the two objectives need to be identified and monitored separately. Combining a current VaR (which should respond quickly) with a stressed VaR (which serves as a buffer against swings in volatility), as required under Basel III, entangles the two objectives; backtesting for accuracy becomes almost impossible unless the two ingredients are separated. Loan loss provisioning in which banks build reserves before credit quality starts to deteriorate and then draw on these reserves in a downturn can combine accurate risk measurement with countercyclical risk management and allows a separation between measurement and buffering. Central clearing of derivatives introduces a buffer between dealers while maintaining incentives, through default fund contributions and margin payments, for the clearinghouse and its members to monitor counterparty risk. None of these examples offers a perfect solution but they illustrate the point that part of best practices in risk management, as viewed from a systemic perspective, should be creating mechanisms that reward precise – and potentially procyclical – risk measurement while damping the amplifying effects of widespread simultaneous responses to an increase in risk.

3. Risk Governance, Incentives and Cognitive Bias (*Clifford Rossi*)

The financial crisis of 2008-2009 underscores the importance of risk governance and incentive alignment for preserving the long-term viability of financial institutions. Widespread breakdowns in risk management of all types in the years leading up to the crisis are well-documented in Congressional panels, class action lawsuits and bankruptcy proceedings.[19] Despite significant advances in analytic capabilities that were supposed to improve the accuracy of risk assessment, fundamental breakdowns in risk management occurred driven by poor corporate governance coupled with senior management cognitive biases. These biases were manifest in poor executive compensation structures that failed to take risk management objectives into account, and marginalization of risk management functions both in terms of stature and financial support, leading to extremely poor identification, measurement and management of risks. Under a weak corporate governance model, management may have

[19] The Financial Crisis Inquiry Report (2011)

greater opportunity to influence their compensation structure with an eye toward maximizing their utility. Management cognitive biases may help shape performance objectives used in setting their compensation. In this process, risk management actions that reduce the chances of achieving target performance objectives may be resisted by management. Cognitive biases may then lead to management outcomes that marginalize the impact of risk managers to the business.

Enactment of the Dodd-Frank Act has in part attempted to regulate improvements in risk management by requiring risk committees of bank boards be established for firms over $10 billion in assets, and requiring risk expertise on boards, among other changes to bolster risk management. Cognitive biases of senior management are difficult to regulate if even possible, and thus a set of complementary actions are required to attack deeply rooted cultural institutional attitudes toward excessive risk-taking. A well-established body of literature exists on executive compensation, incentives and risk-taking. Another important strand of research explaining risk decisions under uncertainty is found in behavioral economics. Building on the work from these two areas, this section of the paper establishes a model describing the relationship between incentives and the effectiveness of risk management functions within the corporate structure. This section shows how poorly designed executive compensation structures can lead management to marginalize risk management units and how limitations in data and analytics facilitate this process. Understanding these behavioral effects provides insight into what policies may be useful in driving toward effective risk management outcomes.

Strengthening financial incentives for management to instill a strong risk culture in an organization can be accomplished in several ways. For example, external groups critical to the firm's viability and ongoing operation such as rating agencies, regulators and directors and officers liability insurers could elevate the focus on risk management practices by reflecting this more in their ratings and premium structures, including risk-based deposit premiums. Adoption of risk-based performance metrics used directly in setting executive compensation is another mechanism that can address incentive alignment issues between management and shareholders. Strengthening the ties of risk management to the board is also essential as is raising the situational awareness of risk managers to assess and internalize both firm-specific and potential systemic risks facing the industry.

3.1. A Bank Risk Management Model

Risk management at financial institutions differs in large measure from that of nonfinancial companies in that risk is a primary ingredient in the development of products and services of financial services companies. For purposes of exposition, a distinction is made up front between risk management and business management. The former group is responsible for identifying and measuring risk and proposing and/or taking actions to mitigate risk. Business management has responsibility for overall profitability and related objectives for a line of business. As a result, it is natural that business management will take an active interest in participating in risk discussions.

Complicating these discussions is the fact that risk management is largely an exercise in quantifying uncertainty and then working to find ways to mitigate risks outside the company's risk appetite. These two features of risk management; a deeply rooted connection between risk and product and uncertainty give rise to a set of behaviors that when present can lead to significant breakdowns in risk management, potentially jeopardizing the health of the firm. So while much of risk management over the last decade or more has witnessed a remarkable evolution into a highly analytic-focused discipline, the fundamental drivers shaping risk-taking are rooted in moe subtle behavioral characteristics.

Following the demise of several well-known large financial institutions during the crisis, a number of Congressional inquiries and bankruptcy investigations identified a wide range of risk management breakdowns. These include evidence at Lehman that senior risk managers were marginalized during discussions of strategic business issues and a lengthy history at Washington Mutual (WaMu) of limiting the involvement of risk management in critical areas of the business.[20] In yet another example, affirmations by ex-risk managers at the subprime lender New Century echoed these themes at larger companies.[21] With so many anecdotal examples regarding poor risk governance apparent during the crisis, a natural question is what explains this behavior?

Research from areas investigating behavioral responses to financial risk-taking and agency costs related to incentive conflicts among corporate stakeholders serves as a useful theoretical backdrop for developing a working model explaining drivers of business management

[20] Valukas (2010) and FDIC (2010)
[21] Lindsay (2010)

biases toward risk management. The academic literature tends to support the view that weak corporate governance structures open the door for managers to impose greater control over the design of their compensation packages.[22] If so, then these incentive structures provide the vehicle through which firm risk-taking is defined. Focus on short-term rewards and performance metrics that ignore or minimize risk views from risk managers then set the level of risk-taking for the firm. Bringing this concept together with work on cognitive biases from behavioral economics establishes the linkage between incentive compensation structures and risk governance.

In their work, Bebchuk et al. outline differences between optimal contracting and the managerial power model to designing incentive compensation packages for executives. In an optimal contracting framework, the objective is to minimize agency costs between management and shareholders. The authors further contend that boards do not always act in an arm's length fashion with respect to senior management and over time for various reasons may become captive or overly influenced by a powerful CEO. This allows management to maximize their own utility at the expense of shareholders by influencing the design of compensation contracts allowing them to extract rents. Management cognitive biases regarding competitor behavior, risk-taking and their own priors regarding expected performance, operating in tandem with "managerial positional power" form the basis for suboptimal risk governance outcomes.

A critical contribution of the work to the expected utility-choice model is in describing asymmetries between gains and losses affecting an individual's risk decision. Barberis, Huang, and Santos leverage this work as well as that of Thaler and Johnson to show how an individual's risk-taking is dependent on prior financial outcomes.[23] Specifically, within the standard utility model, Barberis et al. append a term representing utility that comes about from changes in the value of an investor's financial wealth. This is described formally as:

$$\text{MAX} \quad E\left[\sum_{t=0}^{\infty}\left(\rho^{t}\frac{C_t^{1-\gamma}}{1-\gamma}\right)+\beta_T\rho^{t+1}\upsilon\left(X_{t+1},S_t,z_t\right)\right]$$

Where the first term on the right-hand of the expression represents the standard relationship between consumption, C, and utility, ρ is the discount rate, and γ is a parameter governing the shape of the utility function with respect to C. For our purposes, the second term of is of more

[22] Bebchuk, Fried, and Walker (2002)
[23] Barberis, Huang, and Santos (2001), Thaler and Johnson (1990).

interest. The function $v(X_t,S_t,z_t)$ represents the amount of utility derived from changes in the investor's financial position. X_t in this term reflects the gain or loss in investment over some time period, S_t represents the actual financial holdings at time t, and a state variable z_t relates investment gains or losses in a previous time period to S_t. The effect of prior financial performance is related to an historical benchmark in their model designated as Z_t, such that $z_t = Z_t/S_t$. Should $S_t>Z_t$, the investor experiences gains sometime in the past. The significance of this outcome is that investors become less loss averse if prior financial performance has resulted in financial gains rather than losses. With this framework in place, it is possible to describe management risk-taking at financial institutions and how it relates to their risk management functions.

Business management at a financial institution faces a similar utility function as described by Barberis et al. for investors. In this example, the term v(…) is replaced with $\theta(I_t)$ where θ represents the contribution to management utility due to changes in firm financial performance and I_t represents management's incentive compensation structure through which financial performance is measured. Business and risk management biases at banks can be described leveraging the seminal work by Kahneman and Tversky on prospect theory describing risk-taking behavior as well as their work on cognitive biases.[24] Management incentive contracts are later described to be a function of a set of cognitive biases driving their risk-taking behavior. Central to this model is the linkage of incentive compensation structure to changes in risk-taking. Incentive compensation as mentioned earlier is a function of the firm's corporate governance structure with weaker governance exemplified under the managerial power framework permitting incentive compensation structures that allow for greater risk-taking. In that regard, changes in business management utility are related to θ in the following way: $\frac{\partial E[U]}{\partial \theta} > 0$, implying that as a firm's financial performance improves, it raises management utility. Incentive contracts can lead to greater utility as a result of a set of performance measures poorly reflecting a longer-term view of performance adjusting for risk. Although the performance metrics of these contracts may lead to favorable compensation outcomes for management in the short-term, they are illusory. The primary transmission mechanism for this relationship then is the incentive compensation structure. We further describe I_t as a function of several factors driving

[24] Kahneman and Tversky (1979)

management's "view" of firm performance. This view of performance is a reflection of the underlying performance metrics embedded in the incentive compensation arrangement. This might include for example, measures of firm profitability, stock performance (such as price-earnings ratios), market share, among other possible metrics. Performance metrics established in incentive contracts designed under conditions explained by the managerial power model are related to a set of management cognitive biases well-established in the behavioral economics literature.

One of these behaviors relates to *confirmation biases* that assign greater weight to information supporting a particular view.[25] This bias may be associated with the "house money effect" described by Thaler et al. where prior financial performance influences an individual's risk-taking. In this context, a prior period of sustained favorable financial performance would be a confirming event of future strong performance thus reducing management's level of loss aversion. Kahneman also refers to an "illusion of validity" where overconfidence in a particular view or outcome is established merely by the coherence of a story and its conformance with a point of view.[26] Confirmation bias and the illusion of validity may be reinforcing biases for managers. Another bias introduced into this framework is *herd behavior*. Shiller, Banerjee and others describe a phenomenon where imperfect information regarding a group (e.g., a competitor) leads to decisions where management follow a competitor's strategy at the expense of their own based on limited information.[27] An example of this would be large mortgage originators such as Countrywide and WaMu following each other's product development movements, which were largely based on relaxed underwriting standards and increased risk layering of existing products. These firms viewed these newer products as having greater expected profitability than existing products based upon formal disclosures of financial performance by competitors of these new products as well as informal information from recently hired employees of competitor firms and other market intelligence.

This herd effect could be reinforced by confirmation bias supported by a period of recent past performance reflecting strong house price appreciation, low interest rates and low defaults. The last bias introduced into this framework is related to the *ambiguity effect*.[28] This bias

[25] Shefrin (2001)
[26] Kahneman (2011)
[27] Shiller (1995); Banerjee (1992)
[28] Ellsberg (1961)

describes a phenomenon whereby individuals tend to favor decisions based on certain rather than uncertain outcomes. Frisch and Baron attribute this behavior to a general desire to avoid alternatives where information may be incomplete.[29] In the context of risk management, the ambiguity effect has a particular role in defining the effectiveness of risk management. First, since forward-looking estimates of firm risk are probabilistic in nature, this introduces uncertainty into management decisionmaking and performance benchmarks used in incentive contracts. Riskier views could reduce the attractiveness of certain products, and potentially lower the performance of the firm and management compensation in the process.

An example of this would be differences in performance between prime and subprime mortgages. Define the firm's return on equity as net income divided by book, or regulatory capital where net income equals interest and noninterest revenues less interest and noninterest expenses of which credit losses are a component. On an ROE basis, applying a 4 percent regulatory capital charge to each loan, and assuming prime and subprime net income of .5% and 2%, respectively, the obvious choice would be to originate subprime loans carrying a 50% ROE over a prime loan with an ROE of 12.5%. However, if risk management offers a more appropriate performance metric adjusting for the risk of each product relying on risk capital rather than regulatory capital, a different result emerges. Assume that risk management finds that the amount of risk capital that should be deployed against prime loans is 2% and for subprime loans it is 10% based on the underlying risk characteristics of the borrower, loan, property and other factors. Using the net income figures from before, the decision would reverse with prime loans preferred (25% risk-adjusted return) over subprime (20% risk-adjusted return). Importantly, the overall profitability of the decision declines from before presumably reflected in bonus outcomes of management.

Compounding the ambiguity effect are data and analytical limitations that at times can reinforce management decisions to adopt riskier products. This can occur through data and modeling errors rendering risk estimates of limited value in the view of management. Furthermore, confirmation bias and herd effects can also reinforce the ambiguity effect. In the previous example, if risk management establishes that subprime loans have significantly higher risk than previous historical performance suggests and that other competitors continue to

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[29] Frisch and Baron (1988)

originate such products successfully in large volumes, weak governance leading to poor incentive structures augmented by these cognitive biases can neutralize the effectiveness of risk management.

To illustrate these concepts more concretely, consider a manager with a utility function as described earlier such that changes in utility are related to outcomes determined by the incentive compensation structure of that manager, $\theta(I_t)$. Extending the discussion by Barberis et al. that managers are more sensitive to reductions in compensation (as might be exemplified by low bonus payouts and option grants) than to increases, reflecting their degree of loss aversion, the relationship of interest is as follows:

$$\theta(I_t) = \begin{Bmatrix} \Pi_{t+1} \ \mathit{for}\ \Pi_{t+1} \geq 0 \\ \delta\Pi_{t+1} \ \mathit{for}\ \Pi_{t+1} < 0 \end{Bmatrix}$$

Where Π_{t+1} represents the gain or loss in firm profitability as described in the incentive compensation contract and $\delta>1$, reflecting the manager's greater sensitivity to losses than gains generally. For this example δ is fixed across scenarios at 1.5, with no loss of generality to the model. In addition, θ is set in three scenarios at .5, 1, and 1.5 which differentially impacts the manager's utility. In turn, the incentive structure is dependent upon the four cognitive biases; confirmation bias (denoted as X), herd behavior (H), ambiguity bias (A) and the house effect (HE) and the strength of the firm's governance structure (G) reflecting the relative positional power of management according to the managerial power concept. The complete relationship of these cognitive biases to incentive structures can be written formally as:

$$I_t = g(X_t, \overline{H}_t, A_t, \overline{HE}_t, G_t)$$

The ambiguity effect in this model focuses on the estimates of risk presented by the risk management team. Furthermore, management takes previous financial performance into account (the house effect) by referencing current performance (e.g., stock price) Π_t against an historical benchmark level Π^*. Thus, cases where $\Pi^* > \Pi_t$ signify situations where past performance has been strong and vice versa. We define this relationship as $\frac{\Pi^*}{\Pi_t} = \overline{HE_t}$ in the model with $\overline{HE_t} < 1$ signifying cases where prior performance has been good, thus lowering the manager's loss aversion. In a similar fashion, we can relate the firm's performance in a given period to a benchmark of performance of other competitors reflected by a composite performance index of Π_t^C as follows: $\overline{H_t} = \frac{\Pi_t^C}{\Pi_t}$. In cases where $\overline{H_t} > 1$, the manager engages in herd behavior. Finally we assume that firm profitability (ROE) ranges from +50% to -50% over the general period of interest. Figure 1 presents a summary depiction of the three scenarios across each ROE outcome and utility.

Figure 7 illustrates how negative return events differentially affect the manager's utility outcomes dependent upon management cognitive biases that affect the level of loss aversion. Consider the baseline scenario where $\theta = 1$. The line segment, as in all three scenarios is kinked at 0. This scenario illustrates that losses have a greater effect on the manager than gains. In scenario 2, where $\theta = .5$, the manager exhibits less sensitivity to losses than in scenario 1 as cognitive biases and weak corporate governance have lowered the manager's loss aversion.

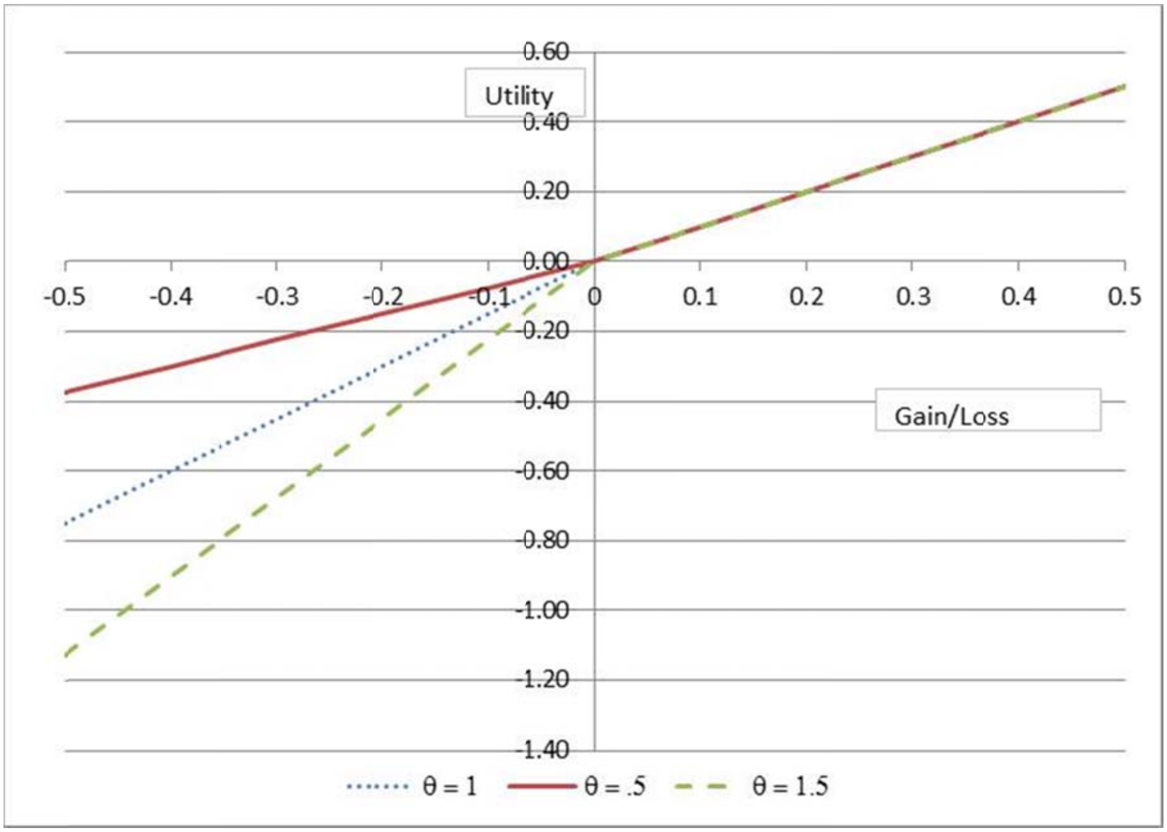

Figure 7

By contrast, scenario 3 (θ = 1.5), the manager exhibits greater loss aversion than the other two scenarios. This outcome could be attributed to a combination of strong governance practices and controls that limit the manager's ability to influence their incentive compensation arrangements and supported by cognitive abilities that limit the potential for herd behavior, the house money effect and ambiguity bias.

Having described the general relationships between governance, incentives and cognitive bias on risk-taking, it is possible to examine how these factors interact with the firm's risk management function. Of particular interest is how data and analytics enter into the process; how the stature and structure of the risk management organization can affect and be affected by management cognitive biases (particularly the case of confirmation bias in the presence of risk management views seemingly more conservative than historical performance); and how marginalization of risk management views can affect firm and management outcomes.

Data and analytics are used to construct forward-looking estimates of risk by the risk management team. In the model, these views enter via the ambiguity effect. Formally, this can be expressed as the following:

$$A_t = f(D_t|S_t, M_t|S_t, \frac{E_t}{E_{t+n}}|S_t)$$

Where D_t represents the quality of the firm's risk data warehouse, M_t is the quality (accuracy) of the models and analytics deployed to estimate risk, and E_t/E_{t+n} reflects the degree to which forward-looking estimates of risk (E_{t+n}) deviate from actual historical risk outcomes (E_t). This relationship is meant to capture the degree to which risk management estimates of future risk outcomes differ from previous experience. In situations where actual historical performance is significantly better than what the risk management team projects going forward, it raises the potential for ambiguity bias and, in the presence of confirmation bias and the house effect can be a reinforcing negative effect toward risk management. It is expected that both errors and deficiencies in data and models reduce the accuracy of risk estimates and thus management's confidence in those projections, further raising the ambiguity effect. Each of the variables affecting ambiguity bias is conditional on the level of stature in the risk organization, S_t. Stature is defined as the level of impact, value and perceived effectiveness of the risk team by management.

The metrics used to define performance play a critical role in shaping incentive contracts and firm and management performance outcomes. Going back to the earlier example of prime versus subprime loan originations, reliance on ROE versus a risk-adjusted metric can lead to demonstrably different outcomes. In the current model then, we capture this effect in the house effect variable (HE) by expressing the general model under two alternative scenarios:

Scenario 1: Non-risk-adjusted $HE_{t,NR} = \frac{\Pi^*_{t,NR}}{\Pi_{t,NR}}$ and,

Scenario 2: Risk-adjusted $HE_{t,R} = \frac{\Pi^*_{t,R}}{\Pi_{t,R}}$

With these enhancements to the model in place, some general observations regarding the effect on risk management can be offered from some simple examples based upon scenario 2 ($\theta = .5$) from before. Keeping the value of the parameter δ as 1.5, we assume that the stature of the risk management team is high and that it has an endowment of data and models that are of relatively good quality such that D_t and M_t imply no change in θ due to A. Recall that scenario 2 assumed a weak governance structure, and hence poor incentive structures leading to lower loss aversion, ceteris paribus. Compare that against a scenario in which the firm's data and models are poor and the stature of the group is low such that together these deficiencies further diminish □ to the level .3. Figure 8 compares the outcomes of

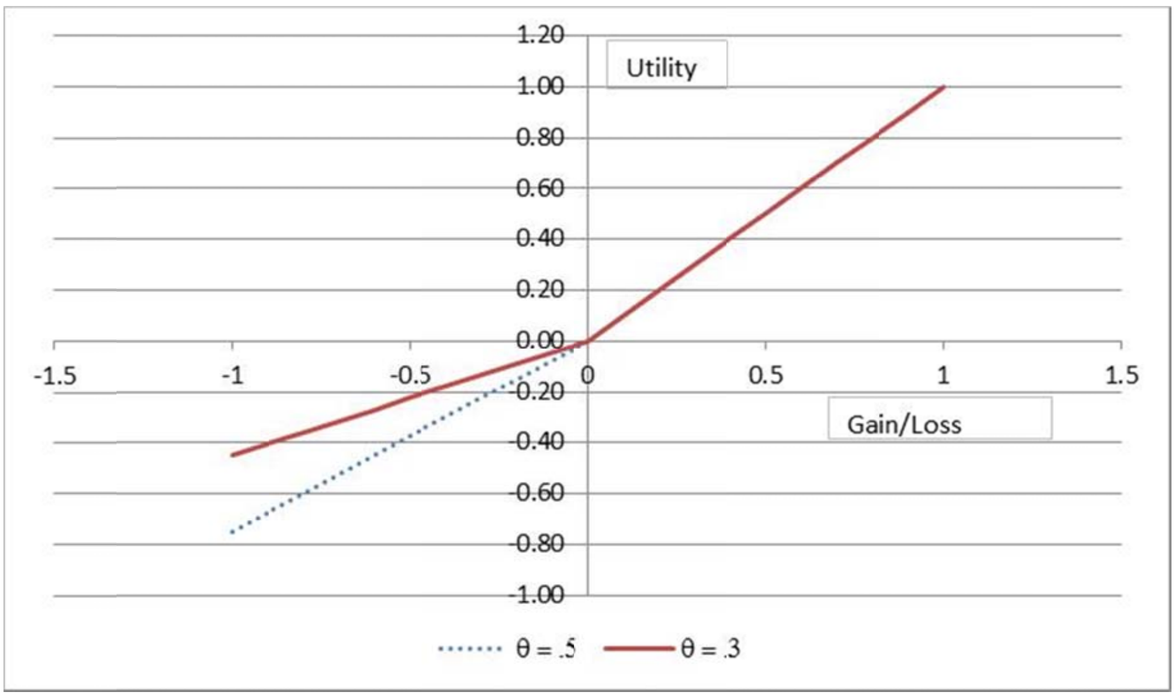

Figure 8

these two scenarios illustrating the point that the ambiguity effect, reinforced by a lack of stature of risk management can amplify the manager's risk-taking posture. Stature might be able to limit the ambiguity effect attributed to poor data and modeling outcomes, particularly if such deficiencies have been rare. A similar outcome as depicted in Figure 8 could occur due to the actual-expected outcomes effect on A. That is, should $E_t/E_{t+n} < 1$, it raises A in the same relative manner as a deficiency in data and analytics and thus reinforcing and even amplifying the confirmation and house money effects.

Now consider the impact of applying different performance metrics in the manager's incentive compensation plan. We compare two scenarios; one where risk is not adjusted in the definition of performance (e.g., ROE) and the other scenario applies a risk-adjusted metric of performance (e.g., using risk capital instead of regulatory or book capital in the ROE calculation). Figure 9 applies the original scenario 2 ($\theta = .5$) and assumes that the manager applies an ROE metric while the risk team applies a risk-adjusted metric which is closer to actual performance but still is measured with some error.

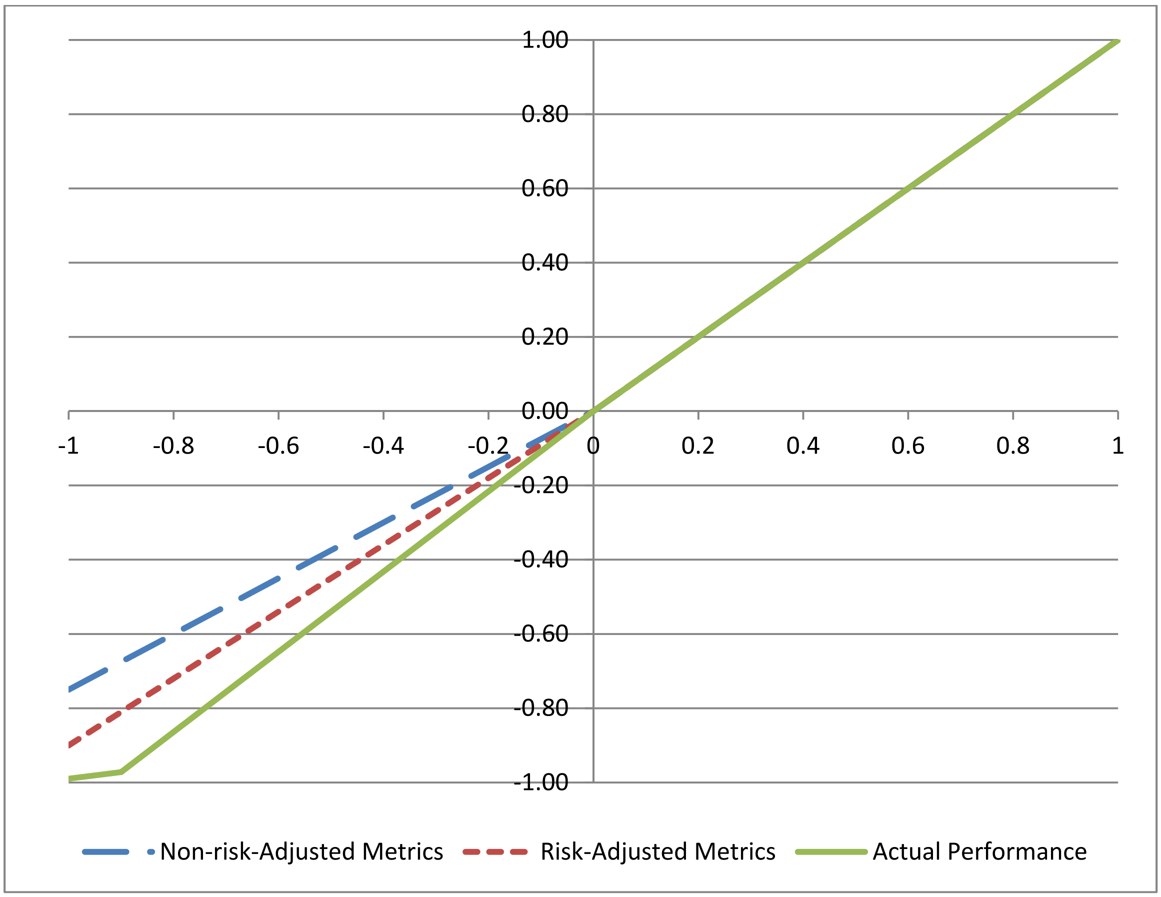

Figure 9

The results from this scenario suggest that when cognitive biases exist in the presence of weak governance, the tendency would be for management to underestimate risk which is compounded by application of metrics not adjusted for risk. Although risk-adjusted metrics are not fully accurate either, adjusting for risk results in expected outcomes that are closer to actual performance than management's views.

3.2. Implications and Policy Options

The model presented above provides a framework for studying effects of banking risk governance from the perspective of managerial cognitive bias and incentives. In that framework we were able to illustrate the linkages between corporate governance and its effect on incentive contracts for management and how that impacts the effectiveness of risk management within the company. The purpose of this section is to draw attention to specific aspects of the model that can contribute to ineffective risk management and propose solutions that can mitigate this outcome. Areas of particular interest are solutions that financially reward institutions and management for maintaining strong risk management processes and controls, align incentives of business and risk managers to view performance on a risk-adjusted basis, and enhance the stature of risk management within the organization.

3.2.1. Financial Incentives

Under the managerial power framework, weak oversight by a board can lead to executive compensation arrangements that are suboptimal for shareholders. Specifically, weak corporate governance creates an environment where management can influence the design of their compensation packages. An array of management cognitive biases can further shape performance objectives that maximize an executive's utility. Actions by risk management that lower the likelihood of achieving management performance objectives create conflicts between business and risk managers. Cognitive biases can negatively affect these tensions, leading to situations that marginalize the effectiveness of risk management units. Crafting a broad-based set of financial incentives promoting risk management best practices could improve management risk-taking behavior. Several organizations are well-suited to provide such incentives. These include companies offering directors and officers (D&O) liability insurance, rating agencies, and safety and soundness regulators.

Over the past several years, D&O insurance has been a target for a number of plaintiffs in civil suits lodged against major banks and financial institutions in the wake of the financial crisis. For example, in 2011 a consolidated class action lawsuit brought against a number of individual and other defendants associated with the collapse of WaMu, the largest bank failure in history was settled for \$208.5M, of which almost \$200M was from D&O insurance. Among the complaints levied in the lawsuit were that management "deliberately and secretly decreased the efficacy of WaMu's risk management policies; (2) corrupted WaMu's appraisal process; (3)

abandoned appropriate underwriting standards; and (4) misrepresented both WaMus' financial results and internal controls."[30] Clearly, the financial crisis has illustrated the risks to D&O insurers and the need to strengthen their due diligence in underwriting their clients. D&O insurance policies are one area where financial incentives to induce management of financial institutions to take greater care in building effective risk governance capabilities could occur. Going forward, such firms should as part of their underwriting review conduct a full bottoms-up assessment of the quality of the risk management structure of the client firm. This should entail a detailed 360 assessment from senior management, the board, and risk management personnel as to the culture, stature, organization and process and controls in place to manage risk across the enterprise. Policy endorsements and premiums would carry a larger weight on these aspects of risk management of prospective policyholders. An example of how such a process could work exists today by one provider that offers indemnification from repurchase liability on mortgages. The MOSA™ Score is developed from an extensive on-site review and survey instrument focusing on the level of quality of risk infrastructure.[31] This includes questions pertaining to organizational structure, and processes and controls in place to manage risk. Weights are assigned to individual risk factors, survey responses and due diligence outcomes. Lender premiums and approval are dependent on the lender's MOSA™ score which provides a composite view of a lender's risk management profile.

3.2.2 External Pressures

Risk assessments by safety and soundness regulators present another opportunity to incent management to adopt risk management best practices. The CAMELS rating process that has been in place for evaluating the quality of a depository institution across categories including capital, assets, management, earnings, liquidity, and sensitivity to market movements should be further strengthened to provide greater weight on risk management practices than they have in the past. For example, between, 2001-2007, the Office of Thrift Supervision (OTS) assigned a CAMELS rating to WaMu of 2, which is defined to be an institution that is "fundamentally sound."[32] In addition, the FDIC determined that while OTS field examination staff identified weaknesses in WaMu's risk management processes to handle their high-risk strategy, they did

[30] Frankel (2011)
[31] The Prieston Group, MOSA™ Score technical documents, 2010.
[32] FDIC (2010)

little to address these deficiencies.[33] OTS has since been merged in with the Office of the Comptroller of the Currency (OCC); however, this example illustrates the oftentimes delicate balance between regulator and regulated entity. The Federal Reserve's revised Bank Holding Company rating system (BOPEC) that has been in place since 2004 features risk management controls and processes as a major component of the rating system.[34] This rating structure provides a useful guidepost for future enhancement of the CAMELs process. Another area where regulatory agencies have the tools to strengthen their oversight of depository risk governance practices is deposit insurance. Development of a robust risk management score that could be tied to risk-based deposit premiums could also promote good risk governance practices.

Another activity that could strengthen risk management is for regulators to have greater input into senior risk manager recruitment and termination outcomes. Although it is fairly standard practice to brief regulators on risk management changes, the regulatory community must have a greater voice in expressing concerns with turnover trends among risk managers, staffing cutbacks in risk functions, and reorganizations that reduce the stature and effectiveness of risk management teams to carry out their responsibilities, among other possible indicators of risk governance problems. Regulators need to translate those concerns directly into the ratings process and inform boards of needed course corrections surrounding deteriorating risk management personnel trends.

Ratings agencies and investor ratings are another leverage point to incent improvements in risk management. Private ratings providers have focused attention in the past on risk governance at the board and senior executive levels; however, these efforts are usually far too general in nature to provide sufficient detail on specific aspects of risk management within the institution. Greater detail must be provided on the organizational dynamics of risk management; how it maintains independence or not, what forums risk management has to present their recommendations and findings about risk, and compensation structures of managers, with emphasis on metrics that are adjusted for risk are just a few examples of the kind of details needed to properly assess risk management.

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[33] FDIC (2010)
[34] Board of Governors of the Federal Reserve System (2004)

3.3 Risk-Adjusted Metrics, Data and Analytics

The model illustrated circumstances under which management would be incented to pursue products and services that might not be in the best long-term interest of the company due to reliance on performance metrics not appropriately adjusted for risk. This is an area that has tremendous potential across the industry to improve decision-making. Deciding what measures to apply, how to weight them and measure them are key issues in development and deployment of risk-adjusted performance metrics into incentive compensations structures.

Although the use and reporting of ROE among firms is fairly widespread, as discussed earlier, such measures do not take into account the underlying risk between assets. In that regard, efforts to measure risk capital are critical to developing such measures as risk-adjusted return on capital (RaRoC) or shareholder value-added (SVA). Data and analytic requirements for these efforts can be daunting; however, the benefits can be considerable in terms of facilitating better capital allocation decisions within the company. As shown in the model scenarios, efforts to ensure data accuracy, consistency, and timeliness of availability are critical not just for modeling, but also for strengthening the credibility of risk management. Poor data and analytics in development of forward-looking views of risk can reinforce confirmation bias and the house effect bias of management. Investment therefore in robust risk data warehouses that integrate various risks across the firm should be taken as a priority for financial institutions. Care must also be taken to ensure that integration of data and systems hosting the data are possible. This includes factoring in such requirements when conducting due diligence of acquisition targets. Not taking into account back-end integration costs can wind up limiting the value of the data for making enterprise-wide risk decisions.

Analytic capabilities, beyond the accuracy issues of model building exercises are crucial to providing a structure around strategic risk discussions at the firm. Measurement errors in addition to mispricing and misallocating capital can undermine the credibility of risk management leading to a reduction in stature of the risk organization if analytic capabilities are poorly designed and developed. Even when such capabilities are robust, risk managers can encounter stiff resistance when cognitive biases are present and corporate governance is weak to analytic views that do not comport with prior experience. The model accounted for such situations in the context of confirmation bias and the house money effect. This can be illustrated by the following example. During the period 2004-2006, home prices had accelerated rapidly in most areas of the country with low defaults experienced in those years. For companies where management cognitive biases were present, it would be difficult for risk management to convince management that alternative scenarios and simulation-based outcomes could lead to both lower home prices and high defaults in the future. Faced with such forecasts, under these conditions, risk managers have limited options other than to document and express their concern and allow their views to be overridden. Resolving risk governance deficiencies then is critical to maintaining a sound risk management capability.

3.3.1. Institutional Risk Governance

Inculcating a strong risk culture within the firm is difficult for firms that have historically not enjoyed such an environment. However, risk culture is a prerequisite for ensuring prudent risks are taken. Development of best practice risk management capabilities is unlikely to overcome cognitive biases and weak corporate governance. In that regard, the financial incentives discussed earlier can reinforce other changes in risk governance within the firm.

The independence of the senior risk officer of a firm is among the most important characteristics of effective risk management. However, organizational independence does not always mean the risk officer is able to completely provide risk views unencumbered from implied pressure from senior management. The reporting structure of risk organizations varies from firm to firm with some Chief Risk Officers reporting directly to the CEO, Chairman of the Board and in some cases the CFO and/or business head, sometimes in a dual reporting framework. Ideally, the CRO or most senior risk officer should report into the chairman of the board of director's Risk Committee, not unlike the typical reporting structure of the general auditor to the Audit Committee of the board. This structure would provide the board with independent views and importantly provide air cover when required over risk views that are inconsistent with the business.

Among the most important tasks the Risk Committee and the board can do in facilitating strong risk governance is to establish a clear vision of the risk-taking posture of the firm. This roadmap would provide management and staff with the board's expectations regarding risk and how it should be evaluated in the context of strategic business decisions. Moreover, to be effective, the Risk Committee should be comprised of individuals either with some form of risk, audit, finance or accounting backgrounds given the complexity of risks across the firm.

As described in the model presented earlier, weak corporate governance practices can lead to poorly designed management incentive arrangements that are focused on short-term results and may not adequately take risk into consideration. Both business and risk management should share a balanced performance scorecard for compensation that reflects risk measures provided by risk management which would be established by the Compensation Committee of the board in consultation with the Risk Committee. Risk managers would not be compensated on production under this incentive scheme. Moreover, business managers should bear a portion of their compensation that is dependent upon certain risk outcomes. For example, losses on loans over time on particular vintages would be measured against expected outcomes and benchmarks of performance established allowing payout of a portion of deferred compensation only when losses are within the indicator of performance. Some issues that come up in such arrangements include how to ensure fair accountability of management to risk performance standards and how to structure contracts with longer-term performance targets.

Another area to improve risk governance entails elevating the situational awareness of business and risk managers from a focus on firm-specific risk to that of the systemic risk to the industry. The temptation to follow a set of competitors is high when coupled with pressures from investors for greater earnings. However, imposing a certain degree of objectivity to understanding key drivers of a set of pervasive industry behaviors can at least limit the degree of herd behavior and myopic focus on individual firm outcomes. Following a course contrary to the industry is difficult, particularly if it leads to a decline in short- and intermediate-term profitability and market share. This is where a strong risk culture at the board level can support a direction by the firm that weights longer-term outcomes more heavily in assessing managerial performance.

3.4. Summary

The financial crisis of 2008-2009 provides an opportunity to study the dynamics of risk governance at financial institutions. Specifically, the large number of failures across the industry, although anecdotal bear a number of similarities. Most failures could be traced back to deficiencies in risk governance and risk management. Lax corporate governance practices enabled management to set incentive compensation arrangements that did not appropriately take risk into consideration. Compounding these problems were a number of cognitive biases so prevalent at the time, that they promoted an explosion in exotic mortgage products and synthetic derivative products with limited historical experience to form sound risk views. Drawing from the extensive academic literature on corporate governance and executive compensation and behavioral economics work on cognitive biases, a model explaining how these factors can contribute to poor risk governance was presented.

Scenarios from this model illustrated how weak governance and incentive contracts can set in motion a series of behaviors predicated on certain strongly held views toward risk-taking. These include confirmation biases that cause management to weight specific outcomes more that align to a particular view; a house-money effect where previous performance factors prominently in management loss aversion, a herd effect where management follows competitor actions based on imperfect information and ambiguity bias that leads management toward outcomes having greater certainty. Scenarios showed that in the presence of cognitive biases and poor governance, risk management can be marginalized and suboptimal outcomes realized.

To better incent management toward implementing effective risk management practices based on the model's structural relationships, a number of important policy solutions are put forward. These include financial incentives such as more rigorous assessment of risk governance and management structures at financial institutions by D&O insurers, rating agencies, and regulatory agencies with assessments tied directly to supervisory outcomes, ratings and policy premiums. The introduction of risk-based metrics into incentive compensation schemes is recommended with particular emphasis on developing robust risk data warehouse capabilities that can support sophisticated risk capital measurement. Opportunities to strengthen risk governance within the company include formalizing the reporting of the senior risk officer to the Risk Committee of the board, establishing a balanced scorecard taking risk heavily into account in incentive compensation structures and raising the situational awareness of risk managers to build the stature of the risk management organization.

4. Systemic Risk (David K. A. Mordecai[35])

The relationship between firm-specific and systemic risk exposures is not always prone to parsimonious description, but tends to share a few broad channels of common interaction and correspondence, largely related to the mechanics of hedging, funding, and margining in support of collateralized borrowing and lending via forwards, swaps, options, and repos. These mechanisms tend to result in a form of leverage via a binding network of value-based commitments which accumulate over time. These commitments cannot be reversed without incurring an unwind cost that will vary with the degree to which actual valuations deviate from expectations (i.e. the estimates upon which the commitments were written). When realized covariances deviate substantially from estimates, acute and sometimes unanticipated increases in leverage result when the accumulation of these residual *basis risks* compound rather than cancel. Hence, the underlying collateral can become systematically mispriced due to a failure to incorporate the conditional sensitivity of collateral values into the leverage calculation.

As such, systemic risk can spread directly via various contingent obligations inherent to bilateral agreements between specific financial market participants (e.g. market-value based advance rates and margin calls typically specified in collateral support agreements related to repo, swap, and credit lines, as well as material adverse change clauses often underlying more traditional lending facilities). Furthermore, financial institutions (even in distinct sectors with neither direct interaction, nor any explicit mechanism for transmission) may share exposure to systematic economic conditions and common market forces, which may be amplified by collective actions that would have been otherwise benign at the firm-specific level.

This section attempts to address best practices and new challenges with regard to monitoring and measuring systemic risk, as well as some elements that are likely contribute to its accumulation. Given the limited space available, spanning the entire topic is infeasible. Instead, I will simply highlight a few key features and conceptually articulate some observations regarding underlying drivers of systemic risk. This section's main focus will be on two topics:

[35] I acknowledge and thank Mark Flannery for his extensive comments and also recognize various colleagues: in particular, Michael Kwak at FTI for his contributions in preparing the exhibits, as well as Compass Lexecon colleagues Peter Clayburgh, George Hickey, and Alex Rinaudo for each of their respective empirical contributions to more extensive works in progress on topics related to this essay. Any opinions expressed are my own as well as any errors that may remain.

1. How, in practice, the adoption of delta-neutral pricing and hedging policies generate contingent obligations that can cause similar risks to accumulate among traders. Individual firms, hedging in accordance with a Gaussian one-period model, might under certain conditions -- in environments where systematic volatility is low, even though in general market instruments might exhibit high idiosyncratic variation and heteroskedasticity[36] -- contribute substantially to market polarization that can result in systemic risk accumulation.
2. The computational complexity of system-wide borrowing and lending (and the related settlement mechanics) produces ancillary contingent forward obligations (e.g. delivery options). These contingencies, commonly deemed to be implicit options, can result in unpriced residual risk factors. These residual risk factors contribute to non-equilibrium price dynamics that undermines both the benefits of cross-sectional and intertemporal diversification, as well as the robustness of delta-neutral pricing and hedging assumption.

Financial Intermediation involves system-wide borrowing and lending (of both cash and collateral) between financial intermediaries, the mechanics of which may not be adequately accounted for by current risk metrics. For example, although hedging activities tend to involve the use of leverage, the effects of leverage related to hedging have typically not been explicitly addressed as a source of residual risk. This credit extension and related settlement mechanics (e.g. margin, clearing, settlement) results in an evolving network of (contingent) obligations which exhibit dynamics that one-period delta-neutral pricing does not capture. In essence, these activities are not riskless, but involve a bet on the future that might be best measured in the context of what has been termed in the industry as *Risk-Based Leverage* ("*RBL*"), i.e. leverage *conditional* upon the realized covariances across exposures. As a *conditional leverage* metric, *RBL* measures state-dependent leverage, the ratio of exposure to capital as a function of changing covariances between positions within a portfolio or across the portfolios of market participants.[37]

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[36] Mordecai (2004) documents and analyzes empirical evidence regarding the effects of residual risk upon leverage when volatility regimes shift from highly idiosyncratic to highly systematic.

[37] Mordecai (2004) also discusses the extensive sources and uses of *RBL* in the trading and hedging activity of all market participants, and further cites as support several post-LTCM policy papers, including the joint working paper circulated by five large hedge funds Caxton, Kingdon, Moore, Soros, and Tudor (2000) "Sound Practices for Hedge Fund Managers" which explicitly documents the role and importance of *RBL* as a risk metric in market practice.

> "… leverage is important…i.e., leverage influences the [magnitude and rate of] changes in the value of the portfolio due to changes in market risk, credit risk, or liquidity risk factors. Consequently, the most relevant measures of leverage are "risk-based" measures…able to modify its risk-based leverage in periods of stress or increased market risk."[38]

The *RBL*, i.e. conditional leverage implicit in the contingent obligations of diverse market participants, may be most simply and consistently expressed using forwards as *basis instruments*. More robust and coherent metrics for quantifying conditional leverage might be the state-dependent sensitivities (i.e. conditional elasticities) for a system of forwards.

4.1. Basis Risk as the Gap between Theory and Practice in Delta-neutral Hedging: Fair Market Value, Delta-Neutral Prices, and Corresponding Market Dynamics Over the Relevant Period

A primary source of the disparity between non-gaussian realizations in the real world and the gaussian assumption underlying the standard delta-neutral approach is the actual setting for the gaussian distribution in the model: (i) a single trader plays (ii) a one-period stochastic game against nature, (iii) where, by definition, the states of nature evolve as a diffusion process. The implications of this setting are quite profound. Everything is exogenous and the trader's actions have no effect upon the underlying asset price (return process). In essence, the trader is a price-taker, i.e. the price setting is defined by construction to be purely competitive, and consequently, the result of the delta-neutral hedging strategy is actually assumed. The standard setting for the delta-neutral hedging and pricing is implicitly, by definition, a one-shot, independent (one-player) game, where the likelihood payoffs are symmetric (i.e. Markov with equal probability of an upward versus downward move) and furthermore the magnitude of probable innovations are small, regardless of the magnitude of the trade made by the actor relative to the size of the market. This is further hardwired into the (Black-Scholes-Merton) delta-neutral assumptions, to constrain the game setting and thereby reinforce the independence and competitive setting needed for the gaussian diffusion process to remain valid within the context of the model (e.g. unconstrained borrowing and lending at the risk-free rate, indivisibly small order sizes, no transactions costs).

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[38] Caxton et al. (2000)

In the standard setting, traders remain independent in making trades, and therefore covariances between either individual trades or traders do not matter (contrary to the real world, where in fact, these covariances and their sensitivities to both changing conditions and strategic responses do matter).[39] In this standard setting, trading and hedging decisions have no influence upon price or return, and information continues to disseminate through the market as a diffusion process. By definition, the delta-neutral pricing framework excludes the endogenous influence of market power or any strategic behavior, regime shifts caused by the adoption of new technology or information innovations. Even when modified to allow for jumps in returns, as with the case of the jump-diffusion specifications for stochastic volatility, the inputs to the model all remain exogenous and the trader's actions (or for that matter any other trader's actions) cannot have any meaningful influence on the statistical properties underlying the return process. In essence, not only does *gamma* as a risk factor (i.e. the potential cost of adjusting the size of the hedge as a result of large price changes in the underlying) not matter under these conditions, but the model constrains trading from influencing gamma. Under these circumstances, how can delta-neutral pricing be deemed to be an informative or effective coordination mechanism for macroprudential governance?

In general, hedging tends to be most commonly discussed within the context of the highly stylized standard delta-neutral setting. In actual fact, this is simply meant to serve as a heuristic and should be openly recognized as such. Practically speaking, in the real world, the actual hedging activities must address those limitations associated with the simplifying assumptions of this single-period, single-trader model with continuous and fully competitive pricing. If the underlying assumptions of the standard model truly held in practice, then the liabilities issued and underlying capital reserved and committed by financial intermediaries in support of contingent obligations would be essentially redundant to the market. A decline in the value of collateral or capital would have no further effects on the financial system. Furthermore, financial markets would tend to exhibit ***neither*** economies of scope ***nor*** scale. In other words, there would be no risk from becoming *Too-Big-To-Fail*. This is clearly not the case. On the contrary, the

[39] In contrast, Holmstrom and Tirole (2001) explore the implications of risk management for the cross-sectional pricing of assets. Rochet and Tirole (1996) discusses the propagation of economic distress via financial transactions as "chains of obligations", e.g. intraday payments, overnight and term lending and OTC derivatives and other contingent claims. The authors advocate collateralization and credit insurance, but do not address under what conditions the mechanics related to these very precautions might actually propagate economic distress.

liabilities of financial institutions tend not to be redundant, markets tend to exhibit scope and scale economies, and as further evidence, derivatives (e.g. futures, options) tend to be more actively traded than the standard delta-neutral model would imply.[40]

Contrary to the practical implications underlying the setting of the delta-neutral model, markets are incomplete and contracting is costly. Because, as stated previously, markets (as well as contracts) are incomplete, hedging is nearly always imperfect and leaves hedgers exposed to some sort of basis risk. A simple and direct transition from theoretically benign delta-neutral hedging to the far greater complexity of real-world hedging activity (and related *RBL*) is the notion of basis risk. Basis risk can be described as the residual exposure resulting from those missing factors related to the simplifying assumptions of the delta-neutral, one-period model setting. As such it is a reasonable way to conceptualize the impact of nonlinear, regime-shifting, non-gaussian price processes on hedging-related contingent obligations.

Hence, the systematic accumulation of basis risk, being an unpriced residual within the delta-neutral setting can have systemic effects.[41] At best, delta-neutral pricing should be strictly a starting point for the purposes of posting indicative pricing. Delta-neutral pricing assumes costless hedging, frictionless markets, perfect replication of the payoffs from the instrument using a ***complete*** set of related components. In the simple one-period (*i.i.d. Gaussian*) case, for example, to hedge the price of a single equity for a forward date: borrow the capital and buy the common, sell the call option, use the proceeds to buy the put option and the price of this equity is hedged for the remaining duration of the vanilla options such that the only remaining cost is the cost of funds (also assumed in the model setting to be riskless).

[40] The dynamically changing but persistent skew exhibited across the term structure of volatilities can also be considered to be evidence for the real-world limitations of the standard delta-neutral model. Additionally, if the set of tradeable securities completed markets by costlessly spanning all states of the markets, in accordance with the standard model of delta-neutral hedging, then there would be no incentive for financial intermediaries to issue structured notes, nor for investors to purchase these instruments.

[41] This can also be the case when markets are engaged in borrowing and lending employing valuations from structural equilibrium pricing models that assume a competitive equilibrium with static covariances and/or statistical independence.

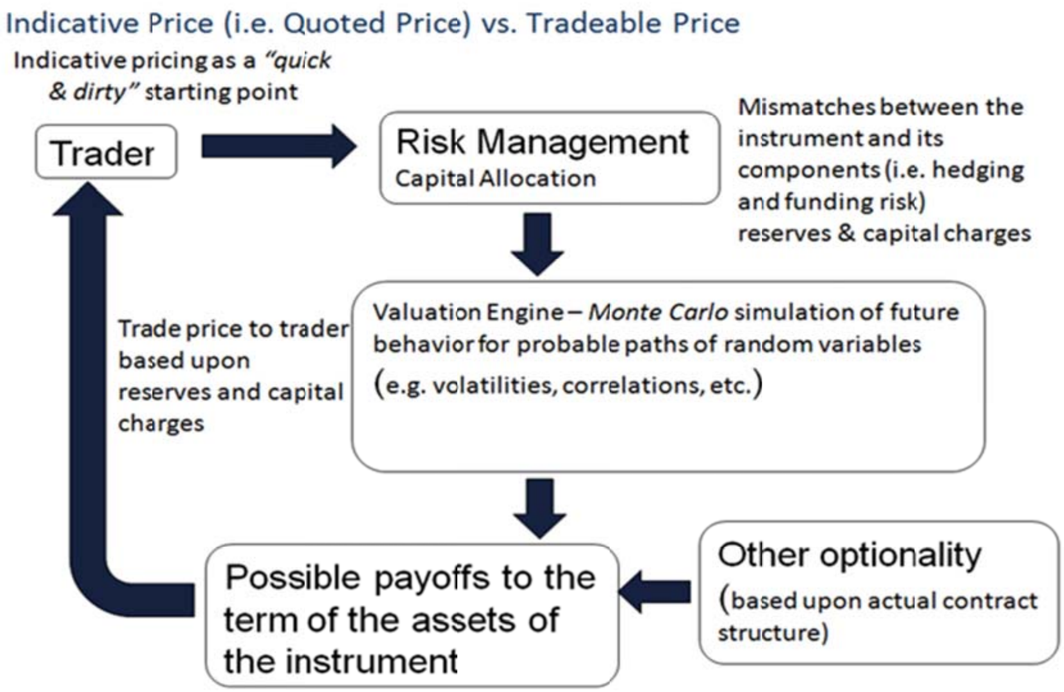

Figure 10

However, in practice, this rarely if ever applies, since in real world settings, the payoffs tend to be more complex, and hence cannot be perfectly replicated. Basis risk results because markets (and contracts) are incomplete. There is unlikely to be a unique delta-neutral value upon which a *Reasonable Buyer* can rely without additional corresponding analysis of market dynamics over the relevant period. Hence, undue reliance upon delta-neutral pricing can tend to be misleading because of model risk resulting from the disparity between the Gaussian assumption in relation to actual non-Gaussian realizations, as well as relevant underlying covariation between the hedger and other market participants.

4.2. Empirical Observations From the Literature: The Materiality of Pricing Residuals, Practical Implementation of Delta-Neutral Pricing, and Hedging in the Real World

As stated elsewhere, in addressing how best to monitor and mitigate the emergence and accumulation of systemic risk, other aspects of risk management must also be considered, e.g. measurement tools and data needs, as well as risk governance policies that recognize and explicit acknowledge the limitations of the standard delta-neutral setting and the sources of disparity with the real world. Within this context failure to account for the potential systemic impact of pricing residuals upon collateralized borrowing and lending could have a devastating impact.

In accordance with the literature, relative to the standard delta-neutral setting, in the real world:

- Regime changes matter.[42]
- Drift matters to the required holding period return.[43]
- Options are not redundant (which implies that delta hedging is not sufficient to replicate the option payoff).[44]
- Hedging does not eliminate risk in practice (residual optionality remains).[45]
- Parametric option pricing models are contradicted by the fundamental asset price dynamics, which matter in the real world.[46]

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[42] "*One key modeling ingredient is missing regime shifts or structural changes ... more likely,<u>the structure of price processes is better approximated by a combination of trend-stationary models with regime shifts</u>. The latter are embodied in models such as the Markov-switching models.*" Fabozzi, Focardi, and Kolm (2010).

[43] "*If one wanted to reduce the time step, more significant than the expectations and variances would be the drift (i.e. the expectation divided by the time-step) and the volatility (the standard deviation per unit time) ... saying that <u>drifts are measure-dependent means that, in moving between measures, the return required by the holder of a security will vary</u>.*" Rebonato (2004).

[44] "*In many <u>practical situations</u> the law-of-one-price arguments we used in the Black-Scholes formula break down. If options really were redundant, it is unlikely that they would be traded as separate assets.*" Cochrane, J. H. (2005)

[45] "*This process of hedging eliminates risk (<u>if our process indeed follows a geometric Brownian motion</u>, **which is not true in practice**), so that the real world drift 'mu' of the stock ... is not relevant to pricing the option.*" Tan (2009). It should be further noted that the author, an experienced practitioner, does indeed emphasize the importance of this point in the original publication with bold text.

[46] "*The term 'parametric' in this [context] is meant to emphasize the reliance of a class of option-pricing formulas on the particular assumptions concerning the fundamental asset's price dynamics. Although these rather strong assumptions often yield elegant and tractable expressions for the option'sprice, theyare typically contradicted by the data, which does not bode well for the pricing formula's success. In fact, perhaps the most important aspect of a successful empirical implementation of any option pricing*

- Drift and volatility dynamics are particularly relevant for risk management.[47]

For example, the time series of returns for the two equities below (Citigroup and Bank of America) both exhibit significant variation in their degree of correlation and relative volatility, respectively.

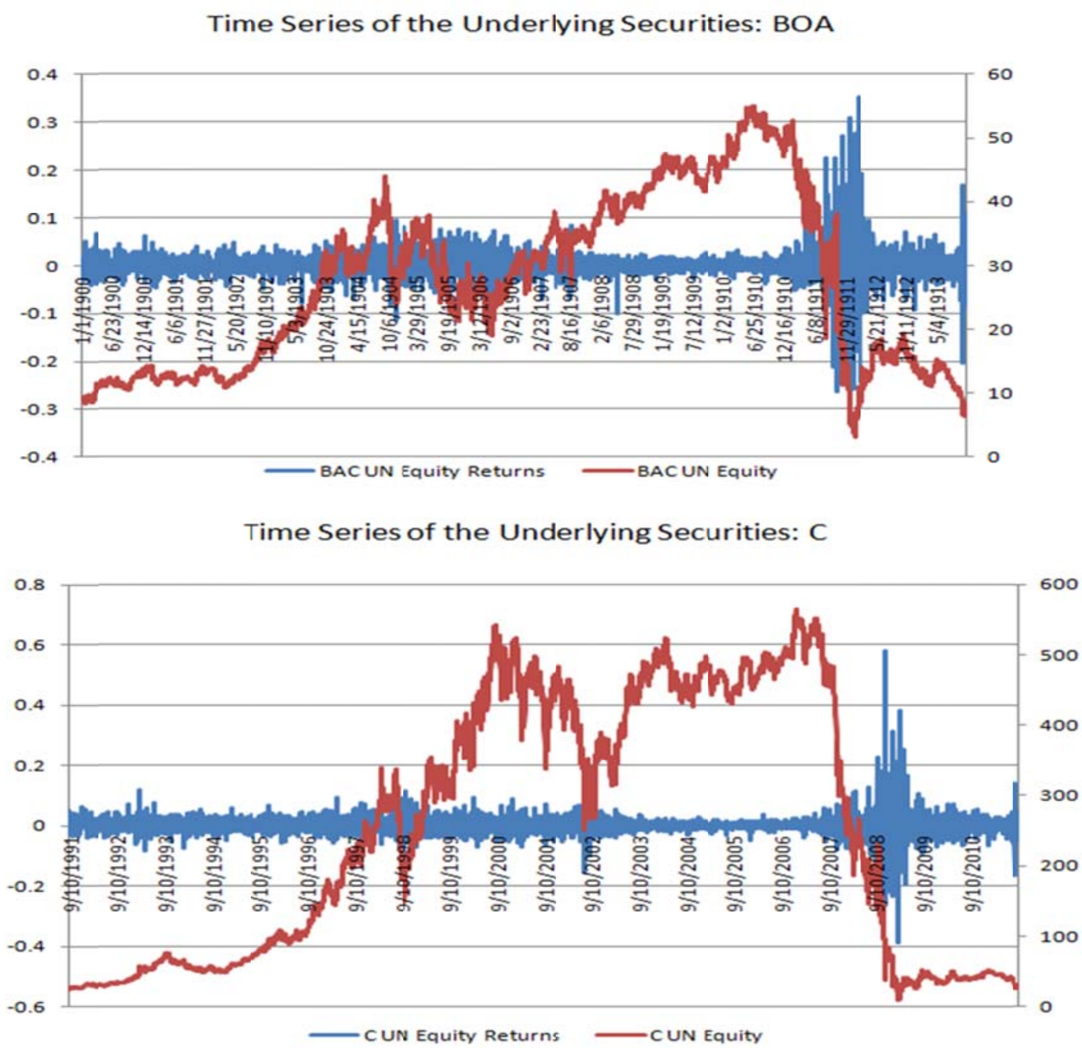

Figure 11

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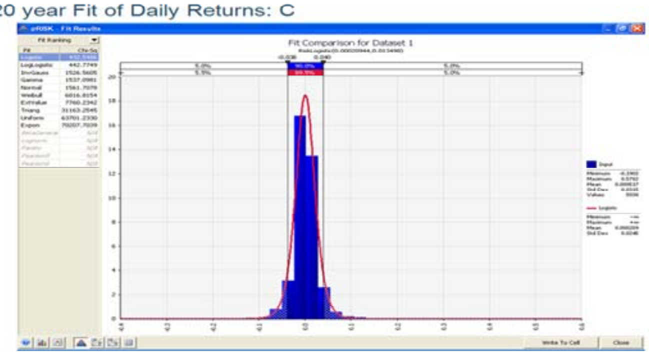
model is correctly identifying the dynamics of the stock price and uncertainty regarding these price dynamics will lead us to consider nonparametric alternatives." Campbel, Lo, and MacKinlay (1996).

[47] "*Needless to say if the estimation were carried out for risk management ... the real-world dynamics (drift plus volatility become of relevance) ... the estimation of volatility (which can only be carried out in the real world.)*"-Rebonato (2006). Rebonato acknowledges the relevance and robustness of the Monte Carlo simulation approach for pricing derivatives introduced by Boyle in 1977 and subsequently established as a standard industry practice, in particular when there is no unique *risk-neutral pricing* measure.

Furthermore, as shown below, the distribution of daily returns are not Gaussian for either security.

20 year Fit of Daily Returns: C



20 year Fit of Daily Returns: BOA

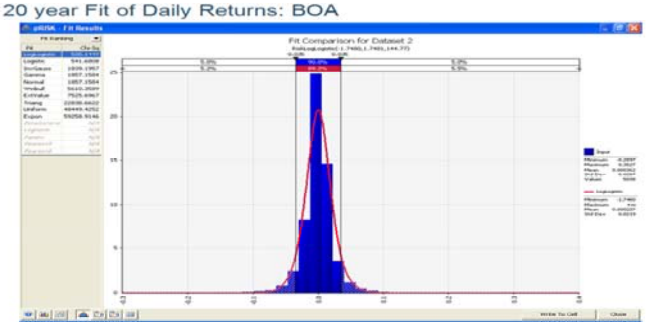


Figure 12

Finally, the daily distribution of returns for either security exhibit substantial nonstationarity. The result is that the empirical distribution of probable payoffs for an "autocallable, worst-to-perform" equity structure written on these two equities (which exhibits payoffs that share some similar properties to payoffs both for long-short strategies as well as certain CDS trades) bears no resemblance whatsoever to a delta-hedged structure.

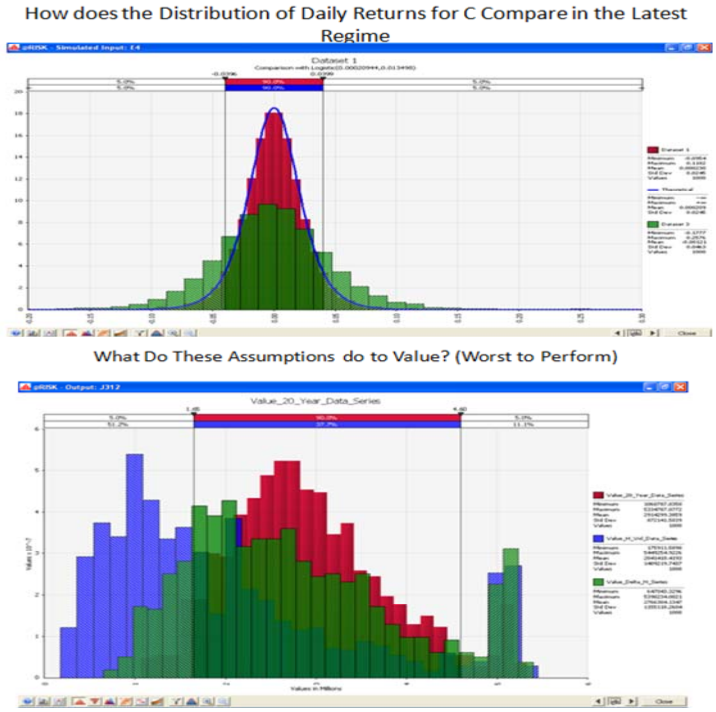


Figure 13

In a non-competitive, non-gaussian setting, strategic trading, regime shifts, information innovations, and market power are all potentially important (and interrelated), and the degree of their relative importance depends upon market conditions and prior history. In a multiperiod setting with multiple (N>1) players, trading strategies (e.g. related to order size and flow, etc.), i.e., microstructure, can result in endogenous price behavior with non-Gaussian properties, and with market power one or more buyers can influence prices. In fact Gaussian diffusion is effectively entropic (informationless), and a very special, rather than a general case.

Although discretionary trading, in and of itself, is likely to be neither necessary nor sufficient for systemic risk accumulation, under certain conditions the optimal exercise of *Cheapest To Fund* ("*CTF*") versus *Cheapest To Deliver* ("*CTD*") options across market participants might (depending upon the network configuration of obligations) result in a destabilizing mismatch, i.e a debt overhang, rather than lead to equilibrium settlement, i.e. market clearing. Consider, for example, lending funds to a counterparty via 90-day term repo involving a corporate bond. It would be natural to hedge your risks in this transaction by advancing only 80% of the market value of the bond (based upon an estimate of the bond's volatility) and to employ some of the additional yield to purchase two single-name CDS contracts on the underlying bond and on the counterparty.[48] Your CDS must have a tenor of 1, 2, 3, or 5 years, since 90-day CDS may not be readily available. When the repo unwinds (at or before its initial maturity), you are committed to residual CDS payment obligations. If CDS spreads have tightened, your position cannot be assigned, unwound, or sold without incurring some cost, which is contingent on the value of assets on the unwind date. That is, these are contingent obligations that result from incomplete CDS markets.

The delivery options inherent in many financial contracts (including, but not limited to CDS) although necessary, also serve as a major contributor to the systemic accumulation of residual risk. The related substitution effects resulting from the sudden shift in the "state" (i.e. the value) of these delivery options (relative to the contemporaneous value and ownership of the underlying collateral) often becomes a major pricing factor when a market event occurs. However, the economics related to the mechanics and microstructure of physical delivery and related phenomena (e.g. squeezes, manipulations, etc.), although well-researched in the literature regarding commodities and Treasury futures markets, have been less researched regarding derivatives referencing other underlying collateral. Similarly, some research has been published regarding the economics related to the mechanics and microstructure of Treasury repo activities[49].

It is also worth noting that over 30 years after the introduction of physical delivery for exchange-traded Treasury futures, and over 60 years since the inception of Treasury repo, the nuances of the settlement mechanics for both activities are still being reconciled.[50] By way of illustration and further explanation, CDS are actually credit spread options (triggered by a default event but valued in accordance with spread changes) with an embedded interest rate option that becomes binding through the delivery option premium inherent within the contract. Even for the case of a cash-settled CDS, the delivery option underlying physical settlement will ultimately

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[48] The CDS contracts' hedge ratio is proportional to the covariance between the bond collateral and the exposure to the repo counterparty, net of cash equivalent margin. This also assumes that the covariance remains static and approximately equivalent to the estimated covariance but in reality, being dependent upon many different moving parts, is unlikely for large market movements.

[49] For example, see Fleming and Garbade (2004) and more recently Martin, Skeie, and von Thadden (2011). Copeland, Martin, and Walker (2011).

[50] Since its inception in 1917, the Treasury repo market experienced a resurgence in the 1950s and then accelerating expansion during the 1970s and 1980s with the introduction and adoption of electronic book entry.

impact the equilibrium price via the delivery option premium, since someone, somewhere in the marketplace is likely to assume the risk of owning and delivering the physical collateral.[51]

The valuation of the CDS *basis* (between the CDS and the underlying credit instrument) involves bundling a *CDS* with an *Asset Swap* (essentially the financing of the purchase of the underlying bond through an interest rate swap package). Typically, these are indicatively priced by assuming zero correlation between credit spreads and interest rate swap spreads (largely a function of dispersion dominating systematic volatility), although that is not the case. By definition, the interest rate swap spread is intrinsically equivalent to the residual credit spread that remains from funding the exchange between a floating rate instrument and a sovereign instrument (e.g. a Treasury). When regimes shift suddenly or when markets are under stress, the assumption of statistical independence between credit spreads does not hold.

This "hedged" position remains exposed to unanticipated gaps in the basis between the CDS swap value and the value of the Asset Swap (i.e. the basis between the underlying credit instrument and the interest rate swap or alternatively the futures contracts being employed to replicate the interest rate swap). When the forward curve inverts, the residual credit spreads underlying both the CDS and the corresponding Asset Swap may be likely to widen, hence compounding rather than offsetting exposure.

Financial institutions hold capital in order to protect their creditors against ill effects derived from the uncertain value of these remaining CDS payments. The disparities that often arise for both hedging costs and corresponding valuations of residual exposures related to delivery option between the stylized settings of the standard model and the real-world requires that intermediaries deploy capital to support contingent commitments (to either deliver collateral or pay the corresponding differences in value to settle outstanding obligations) by bridging deviations from the expected performance of assets relative to liabilities.

Collectively, the risk-bearing activities of financial intermediaries essentially serve as a *common pool resource* resulting from borrowing and lending activities in at least two contexts:

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[51] Another example arises if one were to replicate a vanilla swap by hedging with rolling stack of shorter term futures. This "hedged" position remains exposed to unanticipated gaps in the basis between the swap value and the value of the replicating futures contracts when the forward curve inverts, Such breakdowns have been observed, for example in the catastrophic loss experiences of Metalgesellschafte AG stack-and-roll strategy, in the Amaranth Natural Gas futures strategy, or most recently the losses exhibited by the Societe Generale and UBS Delta One programs. The have often been referred to a 1-in-1000 year events, based upon the implicit assumption of independence.

first, in the context of the redistribution of capital through trading among intermediaries to allocate excess capital towards institutions with new or increased risks in the real-economy, and second, in the context of which increased trading as a borrowing and lending activity increases overall investment in the real economy.[52]

In the CDS example, maintaining the viability of that common pool resource depends upon robust and reliable analysis of the dynamics of the CDS premium, the underlying distribution of credit instruments being referenced by the CDS, and their corresponding funding characteristics (both specific to the instruments themselves and the agents financing those particular instruments). In other words, the value of the delivery options for the credit instruments underlying the CDS is intrinsically linked to the relative availability of the underlying reference instruments (and hence to the steepening or flattening of their respective forward term structures). Delivery options and their settlement have resulted in some of the more distorted economic conditions in markets (e.g. collateral squeezes). Even in typically liquid and deep markets (e.g. Treasuries), pledges, hold-to-maturity accounting requirements, as well as repo and *rehypothecation*[53] commitments can drain the availability of unencumbered collateral from the market. The result is that valuing delivery options becomes a function of the relative pricing gap between instruments deemed to be eligible for delivery. Furthermore, shortages in the cheapest-to-deliver collateral can often result in a sequence of delivery failures as each receiver in a chain of deliveries fails to receive collateral, and the costs of obtaining the next cheapest available in order to settle these failed trades begin to accumulate.

[52] In either context, the addition of risk to the overall system would be expected to depress the prices of riskier assets, given increased risk relative to a limited common pool of risk-bearing capital. Therefore, the cost of risk-bearing should rise, which is equivalent to the market value of riskier assets declining, given that capital is costly. Simsek (2010) discusses a hedge-more/bet-more effect whereby traders take speculative positions on new assets, which they then hedge by taking complementary positions on existing assets, which in turn enables them to place larger speculative positions ultimately assuming greater risk. According to Simsek, hedge more/bet more can lead to a greater increase in the speculative component of variance when they are more correlated with existing assets (e.g., when they are derivatives of existing assets), become more susceptible to speculation and further financial innovation is more likely to be destabilizing.

[53] Rehypothecation is the practice that allows collateral pledged by one party to another to secure funds to then be reused and hence repledged by the second party as collateral for obtaining its own funding. This practice increases system-wide lending Singh and Aitken (2010).

4.3. When Basis Risk Becomes Binding: How Systematic Pricing Residuals Become Systemic Risk via the *Collateral Amplification Mechanism*

Systematic (i.e. undiversifiable) risk becomes systemic when it is amplified by the inherent (and sometimes hidden) optionality within the financial system itself, which is primarily a symptom of both market and contract incompleteness. For example, the cumulative effect of the necessarily incomplete hedging of the basis between CDS and underlying instruments could result in deleveraging due to contemporaneous widening (or narrowing) of both CDS and asset swap spreads (or unanticipated twists or kinks in their respective curves). Hence, otherwise benevolent risk-mitigation strategies when collectively adopted by financial intermediaries (or households), could have similar amplification and feedback effects:

- "Liquidity-run" dynamics generalizes the case traditionally documented in the bank-run literature, in which correlated depositor withdrawals involuntarily deleverage a bank resulting in insolvency, and has been observed in various other domains (e.g. Gorton and Metrick (2010), Sachs, Tornell, and Velasco (1996)).[54] Although the bank-run analogy has been recently applied to margin squeezes and other demand-supply mismatches (e.g. repo), it has not been directly related to the mechanics of settlement and the underlying dynamics of delivery option as an unpriced source of systemic residual risk. Since bank balance sheets have shifted from mostly deposit-based funding and traditional lending to other forms of trading, funding, and investing (e.g., even jumbo deposits began trading interbank more than 30 years ago) banks, dealers, insurers and other market participants now tend "to all feed at the same (or very similar) troughs".[55]
- Grossman (2006) acknowledged key similarities between the option replication strategies underlying portfolio insurance that triggered unintentionally coordinated selling into a declining market during the crash of October 1987, and deleveraging observed in the CDS markets. In both cases, exposure to unanticipated market value changes and tight

[54] Gorton and Metrick (2010)

[55] Within this context, the use of the term "payments system" could be perhaps be defined much more broadly than simply Fedwire or CHIPS, and should also refer to trading and funding activities via repo and swaps, along with the related mechanics of margining, clearing, and settlement transactions underlying these funding activities. It is the underlying dynamics of those contractual features implicit to these functions, as funds, capital, and risks get redistributed throughout the system that as "real options" serve as a common source of inherent optionality within the system.

coupling of contingent obligations across participants result in an acute shift from competitive to oligopoly effects upon the level of market prices.

- Similar effects have been attributed not only to the deleveraging of statistical arbitrage strategies during August 2007 (due to unintentionally coordinated contingent put replication strategies embedded in the risk mitigation algorithms across funds), but also in other instances where risk mitigation by the financing desk of banks and dealers may have resulted in unintentional coordinated selling by hedge funds as counterparties, which may have in turn adversely impacted bank and dealer positions. Many of the complex and compound options intrinsically replicated via statistical arbitrage strategies and embedded in structured notes with path-dependent payoffs share the same residual risk characteristics as CDS basis trades. In fact, it has been a common practice to proximately hedge CDS exposures via equity strategies and vice versa (e.g. Equity Default Swaps, capital structure arbitrage, etc.).

The systematic mispricing of collateral, the failure to price basis risk, becomes binding via the network of forward obligations underlying the exchange of collateral for funding and hedging. These adverse effects can propagate throughout the system and be amplified through these borrowing and lending commitments among financial intermediaries. During regime changes, acute and sometimes unanticipated increases in *RBL* result when the accumulation of these residual basis risks compound rather than cancel, as covariances deviate substantially from their estimates.

As previously stated, there have been several cases where risk management and capital adequacy provisions, collateral support agreements, netting/offset arrangements, and accounting and regulatory requirements have incorporated simple linearized measures, such as *VaR*[56], market-value, or ratings -based triggers, that in their implementation would appear to be analogous to the stylized assumptions underlying the delta-neutral setting. It can thereby be argued that accumulated residual risk has been inadequately accounted for with such linearized measures, and may have contributed to both unanticipated triggering, and further exacerbation of

[56] Expected shortfall (*ES*), a coherent, spectral measure of financial portfolio risk, is being adopted as a more robust risk measure than *VaR*. It requires a quantile-level q, and is defined to be the expected loss of portfolio value given that a loss is occurring at or below the q-quantile. Also called conditional value at risk (*CVaR*), average value at risk (*AVaR*), and expected tail loss (*ETL*), as an alternative to *VaR*, *ES* is more sensitive to the shape of the loss distribution in the tail of the distribution. The "expected shortfall at q% level" is the expected return on the portfolio in the worst q% of the cases.

destabilizing pro-cyclical behavior via the collateral amplification mechanism (as described below).

4.4. Irreversibility As A Result of Non-Equilibrium Price Dynamics: A Stylized Description of the Collateral Amplification Mechanism and Pricing Residuals as Basis Risk in violation of Delta-Neutral Pricing

If risk-bearing capacity, i.e. aggregate funding availability) is defined to be a shared commodity (i.e. a *common pool resource*) exhibiting both time-varying and state-dependent scarcity, which although not necessarily storable is effectively comprised of storable inventory (in the form of assets held in reserve as collateral to support commitments). Then, the capital held in reserve is analogous to an inventory buffer that supports borrowing and lending commitments between market participants,[57] where funds are advanced against collateral. Market participants also tend to be sophisticated about recognizing and rationally exercising any delivery contingencies embedded in their collateral agreements. The embedded delivery options reflect the fact that some securities (from among the eligible set of deliverable securities) are *CTD* collateral, which if available would be the least expensive to obtain for delivery to settle outstanding obligations options. But there are also securities that constitute the *CTF* collateral, which tend to be easier to finance and hence less costly to carry.[58] These embedded timing options tend to price like either a long-run horizon durable asset (cheapest-to-fund when the forward term structure is upward-sloping) or a short-run horizon consumption good (cheapest-to-deliver with an inverted or downward-sloping forward term structure when demand for immediate funding exceed supply of available unencumbered collateral). Thus, severe capital

[57] Delivery options and contango-backwardation (i.e. curve inversion dynamics) are intrinsically linked when long (short) cheapest-to-fund collateral and when the funding curve inverts one will seek to either borrow cheaper-to-deliver collateral for delivery or deliver the cheapest-to-fund, which is typically the more liquid collateral, consistent with Myers and Rajan (1995) and as observed during the LTCM Crisis where the more liquid positions of LTCM were sold before more illiquid positions, exposing LTCM and its counterparties to even greater exposure to writedowns with further declines in the value of the remaining illiquid positions. In this context capital held in reserve is similar to buffer stock in the inventory of a commodity firm in accordance with the fundamentals of carrying cost and convenience yield models that have been adopted from commodity forward pricing models and applied to fixed income and equity forward pricing.

[58] These delivery options are commensurate with the timing options that typically drive curve inversion dynamics (alternatively called carry dynamics) commonly referred to when discussing commodity futures market conditions as *Contango* (upwardly sloping term structures) and *Backwardation* (downwardly sloping term structures). Telser (1978).These dynamics are also closely related to credit amplification dynamics described by Kiyotaki and Moore (1997).

reserve drawdowns, i.e. shortfalls, represent shocks to the relationship between current (spot) liquidity demand and expected future asset values.

In a competitive rational expectations model of "storage" regarding the impact of the embedded timing option on spot versus forward pricing, one could assume for simplicity that the “immediate-use” or short duration spot price is driven by a mean-reverting Markov process. One could then simulate the equilibrium inventory for competitive, risk-neutral agents with heterogeneous horizons and budgets. The shock process and inventory rule would then jointly determine the spot and forward price processes. In such case, although the equilibrium reserve and liquidity demand shock processes may be jointly Markovian, the sequence of demand shocks, affects the level of reserves. For example, a “sell state” followed by a “buy state” for assets in reserve does not necessarily result in the same ending inventory for any given agent. By definition, this situation serves as an illustration of path-dependent (and hence irreversible) basis risk.

Further, it can be demonstrated that forwards can represent residual, but potentially costly, cumulative basis risks as follows: If at time t_0, a forward contract between two parties is initiated, which is a commitment to buy (or sell) the underlying, at a specific future date, for a specific price. At inception, the value of this contract equals zero, and the forward price doesn’t change over time but depends strictly on the date this contract was initiated. However, the value of the forward will fluctuate, based upon the performance of the underlying. Hence, at any time $t_n > t_0$, the value of a forward initiated at t_0 is equal to the cost of unwinding the forward position, i.e. the price someone would be willing to pay for the underlying at t_n.

For instance, suppose that at t_0 you entered into a forward contract, in which you agreed to buy the asset at time T for F_0. At time t_n, the forward position could be rolled forward by selling the same asset at some future date for the current forward f_n. The combination of the two forwards you now hold can be interpreted as another forward with a payoff equivalent to the differential between the two forwards. In other words, it is the present value of the difference between the two delivery prices.

So, the relation between the put-call parity and the value of forwards is the same as the value of the difference between a call and a put with equal expiry dates and the same strike price K. This is equivalent to the current value of a forward initiated with a delivery price also equal to K (i.e., the strike price of the options). If the strike prices of the put and call options are equal to the delivery price of the forward (priced to be equal to zero IRR at inception), the difference between the put and call with equal strike prices is equivalent to the value of that forward. It should be noted that in this case, there may be other (otherwise identical) forwards that were initiated at some point in the past other than at t_0, but whose values are not equal to the differential between the put and call.

These have delivery prices that are (possibly) different than the forward initiated at t_0. Hence, at every point in time, several forwards on the same underlying asset and with the same delivery date might be observed. However, these forwards may have different delivery prices and thus their current values may differ, but do not represent an arbitrage opportunity, since the current values of these forwards contracts are accounted for by the variation in the delivery price with respect to the current forward price. Hence, the early *termination* or *"tear up" values* (alternatively referred to as in the industry as the *unwind cost*) of these forwards corresponds to their sensitivity to interim changes in the value of the underlying.

The *terminal value* of a forward position, i.e. its value *at maturity*, depends on the relationship between the delivery price (K) and the underlying price (S_T) at the time of maturity. For a long position the value of this payoff is: $f_T = S_T - K$; for a short position, it is: $f_T = K - S_T$. For liquid assets, spot-forward parity provides the link between present and expected future prices. It describes the relationship between the spot and forward price of the underlying asset in a forward contract. This relationship depends upon an asset's *cost of carry*, which can be broken down into several different components, does the asset:

(a) pay income, and if so, is the payment on a discrete or continuous basis?

(b) incur storage costs?

(c) serve as *a reserve (investment) asset*, or a *consumption (liquidity-preferred) asset*, i.e. an asset held for immediate sale in the spot market? Any asset can serve as a reserve or consumption asset, although its suitability as such will depend upon its its sensitivity to unanticipated shifts in market states (i.e. conditional volatility) i.e.). If the supply of a particular asset is anticipated to become limited, then its expected holding-period return would increase, thereby contributing to an upwardly sloping forward curve for that asset).

For an asset that provides no income, the relationship between the current forward (F_0) and spot (S_0) prices is $F_0 = S_0e^{rT}$, where r is the continuously compounded risk free rate of return, and T is the time to maturity. The intuition behind this result is that the spot and the forward provide alternative paths to ownership and they should therefore have the same price in a perfect capital market.[59]

For an asset that pays known income, such as a dividend-paying stock, the relationship becomes in the discrete case[60]: $F_0 = (S_0 - Ie^{rT})$ is the present value of the discrete income at time $t_1 < T$. The intuition is that holding an income-paying asset rather than the forward permits you to receive that income. Hence the income I must be subtracted to reflect this benefit. For reserve assets, storage costs must also be considered (e.g. hedging and financing). Storage costs can be treated as 'negative income', and like income can be discrete or continuous. Hence with storage costs, the relationship becomes for the discrete case $F_0 = (S_0 + U)e^{rT}$, where $U = Ue^{r_1 t_1}$ is the present value of the discrete storage cost at time $t_1 \leq T$, and u_i(expressed in percent per annum). is the storage cost which is proportional to the price of the asset, and is hence a 'negative yield'. The relevant intuition is that because storage costs make the final price higher, we have to add them to the spot price.

Liquidity-preferred assets can be immediate inputs to the financial intermediation production process for the satisfaction of immediate payment obligations. Due to potential liquidity constraints, there is a benefit from physically holding the underlying asset in inventory as opposed to holding a forward on the asset. These benefits, which include the ability to profit from temporary shortages and to maintain the ongoing process of borrowing and lending underlying the activity of intermediation, traditionally has been referred to as the *convenience yield*. Thus, for liquidity-preferred assets, the spot-forward relationship is for discrete storage costs: $F_0 = (S_0 + U)e^{(r-y)T}$, where y (expressed in percent per annum) is the convenience yield over the life of the contract. Since the convenience yield provides a benefit to the holder of the asset but not the holder of the forward, it can be modeled as a type of 'dividend yield'. However, it is important to note that the convenience yield is a non-cash item, which simply reflects the market's expectations concerning future availability of the asset. If users have low inventories of the commodity, this implies a greater chance of shortage, which means a higher convenience yield. The opposite is true when high inventories exist. A key reason for focusing upon the

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[59] For an arbitrage proof of why this is the case, see Working (1948).

[60] For the continuous case: $F_0 = S_0e^{(r-q)T}$, where $I = Ie^{r_1 t_1}$, for which an example of an asset which pays a continuous yield might be a foreign currency or a stock index, and where storage costs are $F_0 = S_0e^{(r+u)T}$ (or with convenience yield included: $F_0 = S_0e^{(r+u-y)T}$).

discrete case is that in the real world, indivisible time, prices, quantities, and their related discontinuities, matter, as these give risk to residuals that often compound with unanticipated regime shifts or market stresses.[61]

Given the presence of the timing option related to the (net) present-value of forward delivery of funds versus collateral, there is a wide and varied range of forward-price term structures possible in the proposed numerical simulation approach. Each forward curve represents a different combination of poisson (supply or demand) shock, and previous reserve levels across agents. The forward curves are upward sloping in the low funding demand state and downward sloping (i.e. inverted) in the high funding demand state, which tends to be a state with a low prior reserve level. When demand is high and assets in reserve are at a moderate level, then the forward curve can be "hump shaped." In particular, forward prices initially rise as collateral is being sold (loaned) from reserves. For example, one possible artifact of a two-state example (e.g. {high, low} net demand) might be that the aggregated forward curves might be identical in a market-wide level shortfall (since outgoing reserves would, by definition, equal zero given the state). Yet the corresponding spot prices might differ because of differences in the level of incoming collateral resulting in a form of "congestion" or a squeeze in terms of order flow (i.e. where current demand exceeds supply or vice versa). The result would be a dispersed branch-like distribution of the possible states of shortfall.[62]

Even in the absence of a more complex network structure, the main results of simulating the dynamics of a setting as described above would likely be the following: (1) an equilibrium term structure of spot and forward prices, generally decreasing in reserves and increasing in the current Markov shock; (2) endogenous binomial price trees constructed to price and hedge forward basis instruments and by extension swaps options and other contingent obligations; (3) non-constant hedge ratios for long-dated forward positions using short-dated forwards,

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[61] The discrete case bears similarity to industrial organization models of durable goods markets and inventories where supply/demand curve schedules are discontinuous or "kinked".

[62] For example, assume that the value of liquidity (demand for immediate or short term funding) is determined by agent-specific shortfalls collectively driven by an overdisperse poisson process across the risk-neutral agents, and where the poisson intensity is a random variable or even an endogenous deterministic process related certain principal components underlying trading activity (alternatives include statistical properties of network structure e.g. computational complexity and search cost related to state-/path- space). The poisson process in conjunction with the capital rule jointly determines the spot and forward price processes and could conceivably be modeled within a recursive Bayesian hierarchical framework (e.g. particle learning) to yield an extensive system of forward curves conditional upon the states of the agents.

conditional on the current demand shock ***and*** the endogenous inventory level; (4) results generally consistent with an alternative specification modeling forward and spot prices explicitly from economic primitives, where the demand for immediate funding is specified to be an exogenous "dividend" process, i.e. spot prices and funding liquidity premiums are separate stochastic processes where correlation is a function of asset price correlations and hedging demands. However, explicitly modeling the joint evolution of inventory and spot prices although computationally costly should yield more granular information regarding forward price dynamics via corresponding carry dynamics, which in turn relate to the intrinsic consistency property between the spot price and liquidity demand. Furthermore the model should account for the changing landscape of covariances between spot prices and convenience yields, dependent upon these time-dependent options for delivery. In other words, the disparities in value between *CTF* versus *CTD* collateral under different scenarios where corresponding curve changes increase the disparity between underlying collateral eligible for delivery.[63]

By adding information about the network of bilateral agreements between participants, the distribution of capital reserves and correspondent bilateral cross-margining flows, act as ancillary state variables which summarize past shocks, given the evolving network of obligations between agents.[64] These state variables matter because of the *risk of ruin*, i.e. costs related to insolvency and failure to deliver. Hence, neither the spot (e.g. LIBOR) nor the zero coupon (e.g. swap) funding or yield curve are the same as the forward (delivery) curve for a specific asset or instrument. Furthermore, it should be noted that even the posted forward interest rate for funding is actually an aggregate benchmark rate. In fact, each long and short (hedge) position has its own sensitivities, i.e. "elasticities" (e.g. duration, convexity), to changes in aggregate funding costs,

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[63] Calculating exact forward prices would require a tree of ***all*** possible future spot prices. Since the reserve process is not recombining, to determine forward prices to horizon *n* potentially requires, given *m* demand states, each iteration on the order of m^n for each agent (or at least for each coalition of agents). With a discrete grid of 1000 distinct reserve levels, this produces a large but sparse Markov transition matrix that could be used to calculate forward prices of any horizon as well as the limiting the unconditional distribution. The degree to which the impact of approximation errors on prices from rounding the reserve value may or may not be limited depending upon the degree to which states are serially and cross-sectionally diversifying, i.e. a function of the skewness and kurtosis of the underlying asset return distributions. It may be that one can reduce the number of discrete inventory levels needed by choosing a grid based on the equilibrium inventory function. The renewal property implies that one only needs to track paths for an agent or tightly coupled neighborhood of agents until inventory reaches a "shortfall" (insolvency or ruin of an individual agent). Since shortfalls happen with non-zero probability, much of the time inventory may be within only a few liquidity demand shocks of a shortfall.

[64] Adrian and Shin (2009); Pozsar, Adrian, Ashcraft, and Boesky (2010).

which is further compounded by the amount and maturities of the leverage employed to finance the position. So in effect each trader faces a different forward curve, i.e. term structure of delivery for each asset in her portfolio, relative to the aggregate curve. Each specific forward curve would correspond to the underlying sensitivity of that trader's exposure to net residual value exposure to financing/funding spreads and collateral spreads.

For example, in a setting with only two traders, if party A ends up owning all of B's collateral, then the expected value of B's collateral would have to compensate A for any other obligations that B may have to A (e.g. when B is insolvent post-settlement/delivery). Alternatively, what if B also bought a hedge from A, where A has pledged collateral to bind the commitment of the hedge that is more valuable in the low state for B's collateral? B would be better off than A for being wrong about the value of B and is also in a position to hold A hostage over settlement between B's collateral and A's hedging commitment to B. This is true regardless of whether "the low state for B's collateral" means either the low payoff from A to B (in the event of cash settlement), or a low value for the collateral asset (or is *CTD* in the event of physical settlement).[65]

4.5. Some Considerations Regarding Firm-Level versus Market-Level Risk Tradeoffs

This sort of paper has provided only a brief overview of two main issues that unite firm-level and macro-level risks. After addressing some issues related to the single theme of delta-neutral pricing and its limitations as a coordination mechanism as described above, this section outlines some firm-specific versus system-wide risk management tradeoffs in the effort to highlight presently unmet challenges with respect to systemic risk mitigation. This section also attempts to tie systemic issues to what are typically addressed as firm-level risk management issues and to also highlight some other areas that warrant further consideration than they might currently receive:

Tradeoffs between transactions costs and computational complexity versus residual basis risk: Firms should be sensitive to the fact that delta-neutral hedging is different from its textbook examples, and hence, adopt more rigorous, consistent, and coherent empirical measurement of

[65] Furthermore, by extension, in a three trader {A,B,C} setting with cross-commitments from {B to C to A} where B and C both have commitments to A, A seizing B's collateral would undermine B's commitments to C, which in turn could likely undermine C's commitments to A.

often non-linear risk factors, which prospectively can drive systemic risk. The subsequent suggestions endorse broadening the adoption of more empirically robust and rigorous approaches to incorporating the actual statistical properties of compound, non-linear payoffs into industry best-practices and macroprudential governance.

Tradeoffs between agent-specific (obligor and counterparty) risk versus instrument-specific credit risk (in other words, a variation on the residual risk between the CDS and the corresponding funding cost exposures of both the counterparty and the obligor of the underlying reference instrument: In the aftermath of the financial crisis, an earlier trend to [66] monitor and mitigate *counterparty gap exposure* and related operational and payment risks (in particular those relevant to the mechanics of clearing, settlement and reconciliation) has attracted macroprudential focus on the systemic risk when a firm becomes *Too-Interconnected-To-Fail* ("*TITF*"). Important causes and consequences of these developments include the following, however, it should be noted that the system-wide implications of many of these newly adopted policies remain to be tested or rigorously simulated.

- Various structures have often understated the corresponding relationships regarding the reliance by a counterparty's commitment upon the underlying asset dynamics of the instrument being financed. With the proliferation of dual-trigger instruments (e.g., liquidity puts) as well as contingent capital and funding arrangements, the correspondence between liquidity and solvency can often be confounded.
- Contemporaneous spikes in interbank/interdealer funding costs (e.g. TED spread, LIBOR/OIS spread, LIBOR, EURIBOR, EONIA) initially occurring in August 2007 are widely considered to have severely constrained both bank and dealer balance sheets. These spikes also corresponded with the failure of dealers to support the refinancing of auction-rate securities and further triggered the involuntary deleveraging, as well as disadvantageous prepayment of long-term obligations and extension of short term obligations, resulting in chains of collateral delivery failures across multiple markets.[67]
- The pro-cyclicality of previously accepted netting and offset arrangements are now widely recognized to have significantly amplified leverage cycles, thereby substantially

[66] In addition to the reports by the Counterparty Risk Working Group I (1999), also see, for example, the following: Best Practices (1999), President Working Group on HLI's (1999), IOSCO SC-5 (2006).
[67] Shleifer and Vishny (2011). and Caballero and Simsek (2009) both discuss how financial assets provide return and liquidity services to their holders, as well as the central role played by endogenous complexity.

exacerbating increases in leverage during market rallies and exacerbating adverse liquidity and solvency spirals during subsequent declines.

- Although, portfolio compression (via multilateral netting) reduces counterparty risk and the operational challenge of monitoring counterparty risk, the net impact upon the resiliency of network structure remains unclear.
- Similarly, although the Dodd-Frank Act does attempt to bring greater transparency to counterparty exposures and to try to mitigate the accumulation of counterparty risk between individual counterparties by mandating the movement of the most derivatives from OTC trading to centralized clearing, the net impact upon network resiliency also remains unclear, Does the *TITF* issue simply shift from the banks, dealers and other participants to the clearinghouse?

Tradeoffs between funding availability and asset liquidity and its correspondence with counterparty solvency: As market activities evolved, becoming more complex, ongoing reliance upon point-estimate forecasts and linear prediction models, and upon statistics like Sharpe Ratios and Value-at-Risk to summarize risk-reward tradeoffs was widely acknowledged to have mismeasured nonlinear risk profiles in general. As these heuristics became widely adopted and thereby engineered into risk management and capital adequacy provisions, collateral support agreements, and netting/offset arrangements, the tendency toward asymmetric and skewed risk-return payoff profiles is generally considered to have exacerbated pro-cyclical behavior. Although efforts are being pursued to more closely integrate funding with hedging and investment activities, particularly in the OTC derivatives markets, a more coherent framework for applying ensemble methods reconcile multiple term structure models to interpolate pricing curves in accordance with the system-wide impact of common factors and shared optionality underlying funding and collateral arrangements.

Tradeoffs between market risk (asset covariances and funding cost variances) and counterparty credit risks: Over time *credit value adjustment* ("*CVA*"), which can be alternatively described as *negative basis* (in structured note and portfolio swap transactions), as well as *counterparty gap risk*, and *jump-to-default exposure*, has been adopted institutionally as a capital allocation and collateral management practice to support OTC derivatives activity in conjunction with equity and credit correlation trading, netting/offset, and active margin management. To monitor and mitigate unintended system-wide, pro-cyclical consequences of

CVA and netting practices across multiple markets (e.g. the state-dependent contemporaneous shocks to covariances across CDS, equity variance swaps, LIBOR swaps and options exposures), requires joint-modeling of more than the counterparty's default risk in conjunction with the market factors driving values in order to capture *wrong-way risk*. Instead, the challenge to robustly simulating the relevant range of probable outcomes although partly a data constraint, is predominantly the computationally costly issue of recursively modeling the dynamics of the conditional sensitivities of net funding and capital shortfall exposures to changing hedging demand and funding costs as a function of changing asset values and vice versa.

Tradeoffs involving reconciling forward-looking spread risk expectations and fundamental default risk (e.g. credit rating) estimates: The shortcomings of relying on credit ratings, and the ongoing reliance of Basel III capital requirements on credit ratings are related to a much broader issue-- the inability to robustly reconcile conditional default likelihood and severity implied by credit spreads with historical fundamental default estimates, partly due to time-varying and state-dependent asset recovery process driving the loss given default.

Tradeoffs involving changing regulatory incentive structure: Regulatory incentives, particularly rule-based regulation, and other mandated institutional provisions (e.g. statutory and fair-value accounting policies and advance rates) continue to be considered a source of "procyclicality" by enforcing correlated low equilibrium behavior among market participants, loosening capital constraints during expansions and tightening capital constraints during contraction.[68] Although there has been increasing focus upon the potential for risk-based regulations to promote pro-cyclical collective action by market participants, little research has been conducted on simulating the portfolio of implicit compound options underlying the regulatory and institutional features.

Tradeoffs between firm-specific and systemic risk governance: There has been increased emphasis directed toward the risk management function as an element of strategic franchise value and long-term profitability, the role of the CRO, and greater risk governance oversight and accountability by boards of directors. Nevertheless, much more attention could be focused upon both the dynamics of carry as a tradeoff between short-term liquidity reserves and long-term capital reserves, and inter-firm coordination issues related to risk-bearing capacity as a utility and liquidity provision as a common pool resource.

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[68] Geanakoplos (2009)

4.6. Conclusions re: Market Risk

Merton (1985) argues that the primary role of financial intermediation is to provide risk-bearing capacity for non-redundant contingent obligations. According to Merton, risk management is fundamental to the production function and hence to the cost structure of financial intermediaries in their role of providing risk-bearing capacity to credibly support contingent commitments. These institutions redistribute capital to support idiosyncratic risk by transacting among themselves. In collectively extending credit, intermediaries also bridge systematic risk, i.e., intertemporal gaps in the relative performance between assets and liabilities (as described above in the CDS basis illustration). As suggested above, this is also consistent with the arbitrageur represented in the Limits of Arbitrage literature (Shleifer and Vishny 1997)[69], in that financial intermediaries face the same risk of deleveraging.[70]

Given that the funding, liquidity, and credit extension being provided through the collective risk-bearing capacity of financial intermediaries can be deemed to be something of a social good, macroprudential coordination across these institutions requires that they all apply consistent and coherent risk metrics. In other words, it could be suggested that all traders should seek to more rigorously and explicitly incorporate the distribution of delivery option values into trading decisions.

Consistent and coherent risk metrics should enable good risk governance practices, conventions and standards which in turn should promote incentives, performance attribution measures and compensation policies that, being incentive compatible. These incentive-compatible risk metrics are not only informative to decision-makers at the firm level but also facilitate the valuation and internalization of tradeoffs between both short-run versus long-run as well as firm-specific versus market-wide costs and benefits.

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[69] Shleifer and Vishny (1997) first discussed involuntary deleveraging of arbitrageurs. Gromb and Vayanos (2002) discusses how hedging and arbitrage is constrained by leverage constraints. Gromb and Vayanos (2010), survey other literature (e.g. Liu and Longstaff (2004), Brunnermeier and Pedersen (2009) and Kondor (2009)).

[70] Given the institutional and contractual nature of financial intermediaries (and hence financial markets in general), risk management decisions of financial intermediaries tend to be both *state-* and *path-dependent*, and hence often irreversible (i.e. *non-recombining*), which incidentally contributes to their being non-redundant. Yet, as discussed above, often times the conventional wisdom adheres to framing risk decisions in the context of the typical one-period gaussian hedging model.

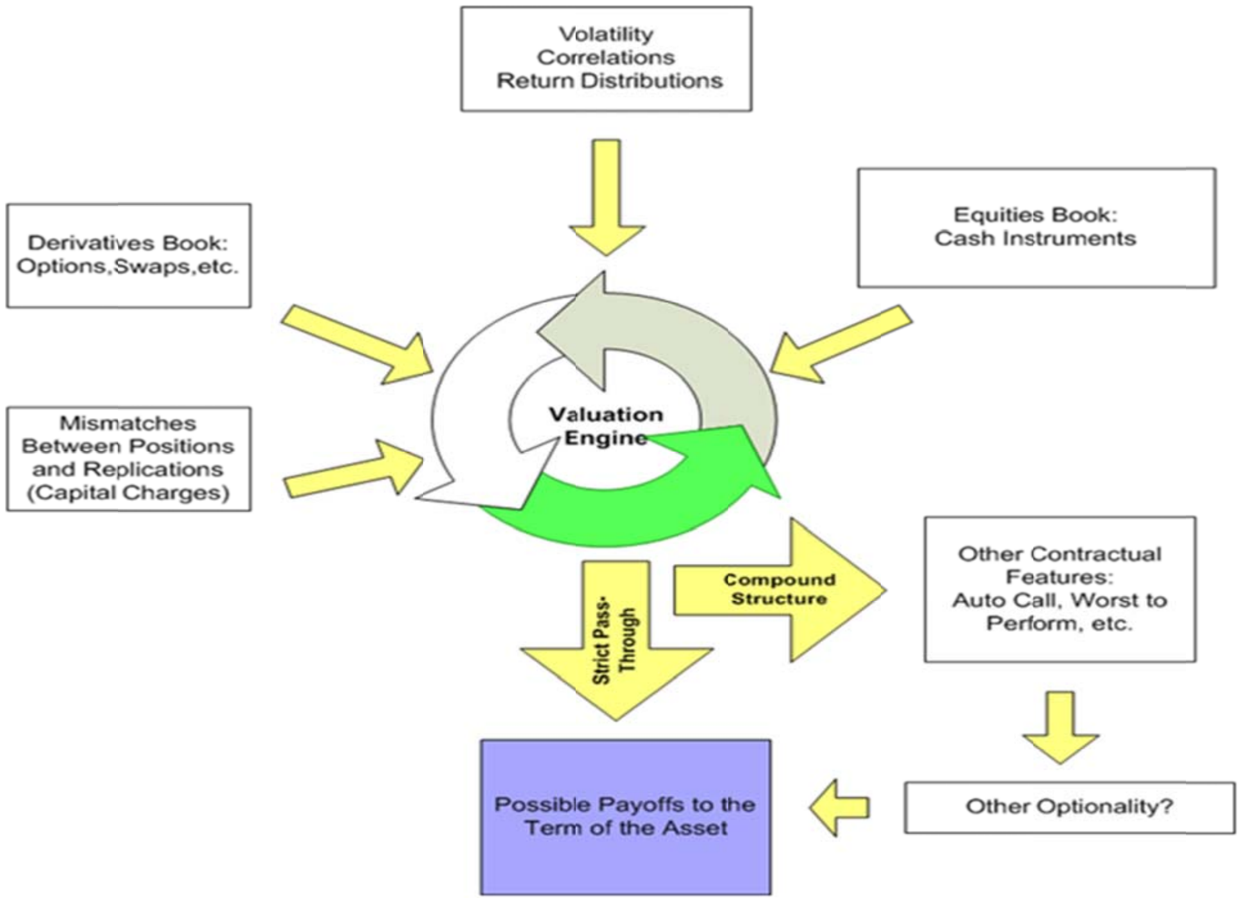

Figure 14

Furthermore, Fair Market Value is based upon what a *Reasonable Buyer*, i.e. the "Marginal Investor", would be willing to pay for the asset (e.g., a structured note involving a path-dependent payoff, or a CDS basis trade as discussed earlier), i.e. the reservation price for the marginal investor.[71]

[71] Essentially the Reasonable Buyer can be classified according to two types: *matched books* versus *buy-and-hold*. Dealers, Hedge Funds and Proprietary Trading Desks dynamically fund and hedge their positions (i.e. a matched book of both funding and hedges, essentially at the all-in-cost of a fully hedged risk position financed over the relevant term). As leveraged counterparties, hedge funds and prop desks are limited by funding and capital constraints of the dealers that finance their activities. For *Buy-and-Hold Investors* (i.e. Pension Funds, Insurers, etc.), the holding period risk-adjusted return analysis should reference all of the same underlying risk factors as the cost of hedging for the remaining life of the instrument. At any time, the price that *Reasonable Buyers* should be willing to pay at the margin includes the price to fully finance and hedge the position to term regardless of the type of buyer. In other words, for the marginal buyer, the price according to the required holding period return and the fully-hedged price should be equivalent, as further explained in Cochrane and Culp (2003).

In summary, the systematic accumulation of basis risk, being an unpriced residual within the delta-neutral setting can have adverse systemic effects. Basis risk results because markets (and contracts) are incomplete. The systematic mispricing of collateral, and more specifically the failure to price basis risk, can become binding via the network of forward obligations underlying the exchange of collateral for funding and hedging. These adverse effects can propagate throughout the system and be amplified via these borrowing and lending commitments among financial intermediaries. During regime changes, acute and sometimes unanticipated increases in risk-based leverage result when the accumulation of these residual basis risks compound rather than cancel, as covariances deviate substantially from their estimates.

5. Summary and Topics for Further Attention

Although the authors of this paper's three main sections conferred while writing, each section essentially stands on its own. At the same time, the overall paper provides a unified assessment of how risk management can be improved. Section 3 then provides some reasons why cognitive biases might lead senior management to under-weight the importance of risk measurement systems, even if they are very good. In considering the business managers' incentives to incorporate risk management techniques, it is worthwhile to observe that risk managers never add anything appreciable to the bottom line. While they may save a firm from disaster, these "saves" constitute unobservable counter-factuals; most of the time risk management is only a cost center.

The technical improvements to risk assessment and the corporate governance elements that impede their full incorporation into business decisions are two broad areas requiring further attention from both practitioners and regulators. We conclude with a list of concepts defining, we hope, the most important areas for continued research or modification of the role of risk management in financial firms' business decisions.

- Firm-level risk management has broadened its scope since the financial crisis, but there remains a tendency to infer risk parameters from relatively short time series. Risk measurement should utilize relatively long data series, which permit analysts to incorporate the potential for regime shifts, e.g. from low-volatility to high-volatility returns.

- Unless risk exposures are incorporated into executive compensation measures, it will be difficult to make senior management's business decisions reflect risk management considerations adequately. This simple-sounding dictum will be very difficult to implement, even in firms with strong corporate governance.

- Firm-level risk management can spill over to create systemic risk through amplifying effects within the financial system. This issue arises in market risk, credit risk, liquidity risk, and counterparty risk. It is part of a broader challenge of aligning incentives between regulation and internal risk management.

- Hedging and risk-bearing are central to the economic role of financial intermediary firms.

- Hedging activities also involve the use of leverage. The prominent role of credit extension in hedging interacts with settlement mechanisms (e.g. margin, clearing, settlement) to create an evolving network of (contingent) obligations within the financial system.
    - One-period, delta-neutral pricing does not capture these dynamics; it ignores basis risk and the endogeneity of firms' positions.
    - In essence, hedging activities are not riskless, but involve a bet on the future that might be best measured in the context of conditional leverage -- what the industry sometimes calls "Risk-Based Leverage".
    - More robust and coherent metrics for quantifying conditional leverage might be the state-dependent sensitivities (i.e. conditional elasticities) of a system of forward prices for risky securities.

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