MODEL RISK AND THE GREAT FINANCIAL CRISIS:
THE RISE OF MODERN MODEL RISK MANAGEMENT

Jeffrey A. Brown **Brad McGourty** **Til Schuermann***

Oliver Wyman

This Draft: 7 January 2015

Abstract

We trace the development of model risk management in U.S. banking against the backdrop of the growing importance of complex financial models in banks, the recognition of model risk, the emergence of model validation as a response to model risk, and the contribution of failures in model risk management to the Great Financial Crisis. We recognize that while substantial progress has been made in the management of model risk, the challenges have grown, including the increasing reliance by the regulators on models.

Keywords: commercial banks, risk management, systemic risk.

JEL Codes: G12, G21.

* Corresponding author: til.schuermann@oliverwyman.com; (212) 541-8100. Brown and Schuermann are Partners and McGourty is a Principal in New York; Schuermann is also a Research Fellow at the Wharton Financial Institutions Center. We thank Michael Duane and Peter Reynolds, the participants of the Federal Reserve Bank of Chicago's 17th Annual Conference on International Banking, and especially its organizer Doug Evanoff. All remaining errors are ours.

1. Introduction

Banking is not simple, even if we want it to be. Banks intermediate between clients displaying a broad set of needs living in a global and interconnected economy. It is naïve to think that bankers can manage by gut feel and "expert judgment" alone. Models are critical to help bankers and their clients and customers to make sense of the complexities of their needs and the product and service offerings.

But with complex models comes model risk, and as with any risk, model risk needs to be managed. The professionalization of model risk management is arguably one of the more significant, and welcome, developments since the recent great financial crisis. There are good reasons for this development: models, or rather the blind faith in poorly specified models, were a significant contributor to the financial crisis itself. Examples abound, but perhaps the poster child examples are the alphabet soup of structured credit products such as CDOs, ABS, CPDOs, and so on. These products require estimation of a complex joint return and loss distribution across the hundreds and often thousands of underlying exposure return and loss distributions. The Gaussian copula – essentially a multivariate normal distribution which "couples" together the underlying possibly heterogeneous distributions – was the model of choice for a very wide range of credit products. The blind faith in this model, and its consequences, is dramatically described in a Feb 23, 2009 Wired Magazine cover page article titled "Recipe for Disaster: the Formula that Killed Wall Street" (Salmon, 2009).

In this paper we give a thumbnail history of model risk management (MRM) over the past two decades to help explain the recent sharpened focus on this discipline. As is, alas, often the case, that focus and corresponding resource expenditure has been driven in part by regulatory pressure, and that pressure has increased dramatically in the post crisis years. We present some examples of model risk management failures, trace regulatory developments in MRM requirements and expectations, and end with a cautionary note given the explosion of models that has come with the CCAR (Comprehensive Capital Analysis and Review) program. Importantly, not only has this dramatic growth in the number and use of models occurred at the banks but also at the regulatory agencies, the Federal Reserve in particular which now relies heavily on models to assess bank safety in the face of stress tests through its CCAR program.[1] Proper model risk management is perhaps especially important for regulators since those models, by design, affect not just individual banks but the entire banking system (or at least the roughly 80% subject to the CCAR program), and are thus a nontrivial source of systemic risk.

To be sure, we are not advocates of making decisions without the use of models. Quite the contrary: we strongly believe that the discipline and empirical rigor that come with formal modeling provide a strong basis for less biased and all around better (e.g. less risky) decision making in banking narrowly and financial services more broadly. We remain suspicious of casual use of so-called expert judgment. However, as long-time model builders (and validators)

---

[1] We will use the term "regulator" and "supervisor" somewhat interchangeably, erring to the more commonly understood "regulator" while recognizing that the use of models by banks is touched by both regulatory and supervisory activities. The distinction between regulation and supervision is subtle, but regulation tends to be prescriptive and formal while supervision is more qualitative and informal. Refer to: *The Federal Reserve System Purposes & Functions*, Federal Reserve Board of Governors, Ninth Edition, June 2005, pp 59-60.

ourselves, we have built up a healthy skepticism for models and view them strictly as decision aids, not decision makers. The crisis has taught us the dangers of "model on, brain off", and as with any powerful tool, it is needs to be accompanied by a tight control structure, i.e. with proper model risk management.

2. The rise of model risk management in banking

Formal models have long been in use in trading rooms at capital markets intensive firms such as the large investment banks, or those divisions at the large global banks. Jorion (2006) describes a short history of the use of models and, more to the point here, their use in the risk management of trading. Typically, the more complex the product, the more important is a formal model for its risk management.

The regulatory response came with the 1996 Market Risk Amendment of the first Basel Capital Accord (BCBS 1996) which allowed for the use of models to assess and determine the amount of capital needed to support market risk from trading. However, the term "model risk" does not appear in this regulatory document.[2] Thankfully, many of those banks affected (and likely some that were not) already had a healthy respect for model risk. Much of the work on derivatives modeling was done by modelers trained in the physical sciences, some of whom were aware of the differences between those models and the primarily statistical models used in finance; see for instance Derman (1996).

A rather dramatic example of poor model risk management can be traced to the demise of the hedge fund LTCM (Long-Term Capital Management) in 1998. LTCM's overly optimistic assumptions of market liquidity needed for seamless hedging are well known. Jorion (2000) presents a rich picture of simple failures in their risk measurement and management framework of value-at-risk (VaR). The firm used VaR results to assess its level of riskiness, and thus required capital, analogous to the Basel Market Risk Amendment of 1996. The VaR approach, which continues to be used in risk management to assess market risk, relies on several key inputs that will impact the level of conservatism (or lack thereof) in the modeled results. Jorion identifies several inputs and assumptions used by LTCM that contributed to a significant underestimation of risk.

Jorion (2000) provides a nice example of a typical LTCM trade. One of LTCM's strategies was to go long corporate debt and short U.S. Treasuries (as a hedge). This strategy works well so long as the correlation between the two positions is sufficiently high. The assumed correlation was around 96%. The implied monthly volatility for this position was around 8.1%. But if the correlation were to drop to 90%, that volatility would go up to 13.6%, and if it dropped further to 85%, the monthly volatility would increase to 19.2%, now more than double the assumed position volatility. Jorion (2000) points out that the empirical correlation was as low as 75% just six years earlier in 1992!

---

[2] By contrast, the most recent version of the Basel Capital Accord, Basel III, makes explicit mention of the importance of model risk; BCBS (2011).

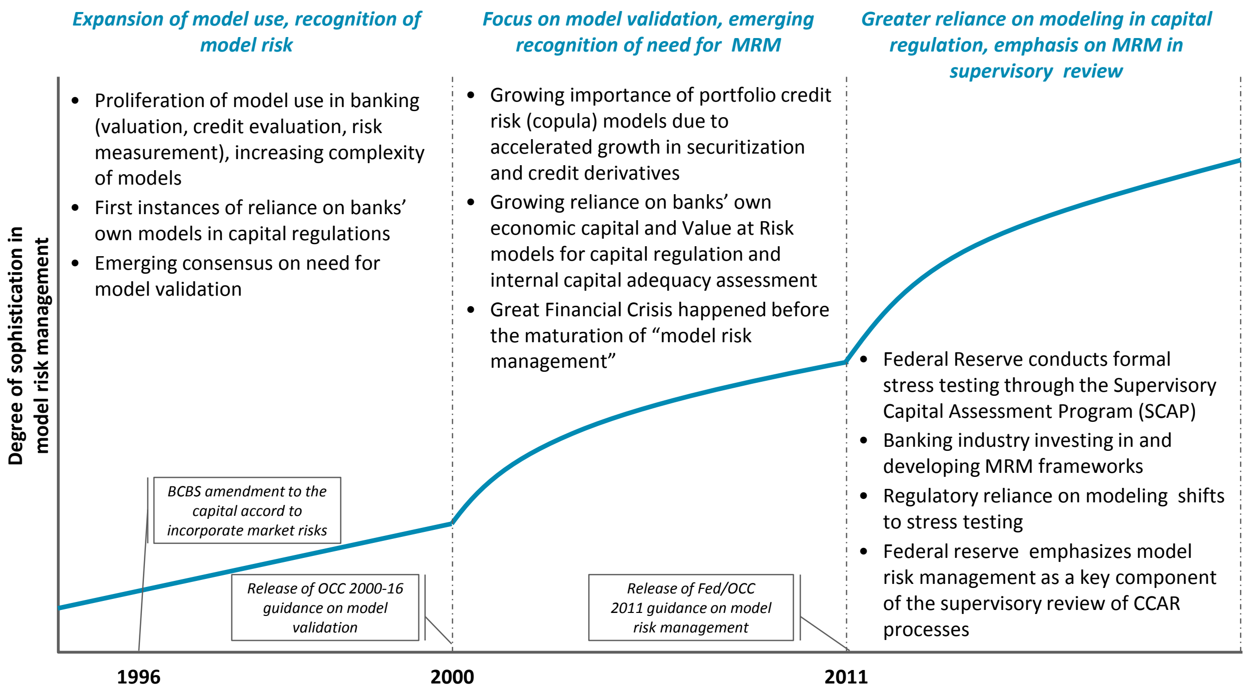
More broadly, model related lessons from LTCM include:

- Volatility was assumed to be constant; in reality, one could expect volatility to increase significantly during periods of market instability, as demonstrated clearly by the development of dynamic volatility models like ARCH (Engle, 1982) and GARCH (Bollerslev, 1986)[3]
- Returns were assumed to be normally distributed (i.e., symmetric and with well-behaved tails), though it is well-known that asset returns are fat-tailed and often skewed (see Diebold (2012) for a recent survey)
- The time period used to establish model parameters was relatively short and did not give sufficient consideration to historical market downturn events (e.g., the crash of 1987)
- The 10-day horizon prescribed in regulatory guidance may not be adequate for a hedge fund, where investments may become illiquid and the time to raise new equity may be substantially longer, particular during times of stress

In Figure 1 we provide a simple illustration of the rise of model risk management over the last two decades. We divide this time span into three periods. The first is pre-2000 which saw an expansion of model use and a gradual recognition of the corresponding need for model risk management. This period saw a proliferation of model use in banking (valuation, credit evaluation, risk measurement), and an increasing complexity of models generally.

[3] The assumption of static volatilities has been a common source of series model risk. Another example is the bankruptcy of Orange County due to the long duration strategy by its investment manager, Robert Citron.

Figure 1: Evolution of model risk management (MRM) in U.S. banking



An important step in model risk management is independent model validation, and by the mid to late 1990s we saw the birth of independent model validation functions within banks. In 2000, the OCC issued its seminal guidance ("OCC 2000-16") to banks on model validation:[4]

> *"Model development is a complex and error-prone process."*
>
> *"Fortunately, model risk can be considerably reduced. Sound modeling includes rigorous procedures for 'model validation.'"*

The key insights of OCC 2000-16 were that all financial models are subject to errors, that certain key procedural activities need to be followed to attempt to identify and eliminate those errors, and that those activities need to be executed by qualified and independent parties. Those activities were then largely adopted by the Basel Committee in the requirements for model validation of the internal models that were the centerpiece of the "Basel II" risk-based capital regime, an early draft of which appeared in 2001. And indeed the U.S. capital regulation implementing Basel II (the Advanced Approaches) requires validation of the advanced systems on an ongoing basis.[5]

The rise of formal regulatory pressure on firms to conduct model validation is a key development of the second phase illustrated above. This period – roughly 2000 through the end of the financial crisis – also marked the rapid development and adoption of complex credit instruments through securitization. In the years prior to the financial crisis, securitization was a

---

[4] Office of the Comptroller of the Currency, OCC Bulletin, *Model Validation*, OCC 2000-16 (May 30, 2000)

[5] 12 CFR, Part 225, appendix G, Section 22, (j)(4).

powerful tool for banks to manage their credit exposure by tapping new investors hungry for highly rated, yet higher yielding, fixed income assets. This allowed banks to free up capital in order to originate more credit (e.g. make more loans such as mortgages). However, the complex structure of those securitizations, including MBS, was not fully understood by banks or investors, or by the rating agencies. Indeed, the models used to value these products and assess their riskiness relied on key assumptions that, if even moderately incorrect, would produce dramatically different results.

Using an example of a relatively simple subprime RMBS (simple because the underlying asset pool was quite homogeneous), Ashcraft and Schuermann (2008) show the confidence of the structurers, and the rating agencies, in being able to accurately determine the riskiness of different tranches of the return and loss distribution. One of those tranches was only 70 basis points wide (at issuance it was rated BB+ and Ba1 by S&P and Moody's respectively), presuming an astounding degree of model accuracy.

Return and loss correlation, or dependence more broadly, is a core modeling feature of all credit securitizations and, of course, re-securitizations like CDOs. Models commonly used in the years prior to the crisis to value securitizations relied upon a "Gaussian copula function." an approach widely attributed to financial engineer David Li. The approach was attractive in that it offered a simple solution to analyze very complicated securities using data observed from credit default swap transactions. For example, the Gaussian copula is a default choice in the popular FinCAD software. Felix Salmon (2009) described the breathtaking speed and impact of this model in his Wired Magazine article. It is worth quoting from this article: "During the boom years, everybody could reel off reasons why the Gaussian copula function wasn't perfect. Li's approach made no allowance for unpredictability: it assumed that correlation was a constant rather than something mercurial. Investment banks would regularly phone Stanford's Duffie and ask him to come in and talk to them about exactly what Li's copula was. Every time, he would warn them that it was not suitable for use in risk management or valuation."

Elsewhere Duffie (2007) has demonstrated that the Gaussian copula model was generating results that should have revealed that model to be invalid for pricing and hedging and, indeed, generated inconsistent pricing across tranches of a given securitization. "If the pool correlation parameter necessary to price one set of tranches is not close to the pool correlation parameter necessary to price another set of tranches then the model is not appropriate." (p.41). Duffie (2007) illustrates this inconsistency with the hedging failures stemming from a May 2005 GM downgrade and its impact on the CDX, an index of credit derivatives, pointing out that the pricing reaction for the desired hedging position had the wrong sign. "Rather than reducing their losses, hedgers following this approach slightly *increased* their losses!" (p. 42).

Credit derivatives are an easy target for model bashers, but the salient point is that the models featured recognized risks that were not managed. In a cleverly titled paper, "Credit Models and the Crisis, or: How I learned to stop worrying and love the CDOs," Brigo, Pallavicini and Torresetti (2010) respond to the "hysteria that has often characterized accounts of modeling and mathematical finance in part of the press and media, and the demonization of part of the market products related to the crisis, such as CDOs and derivatives more generally." (p.1). They argue that model limitations were actually more widely known than often attributed before the crisis, even if not always formally implemented into a given firm's risk management program via formalized model risk management. For example, the model was typically calibrated on the loss of a pool of loans as an aggregate which is not useful for creating hedges for single names. Models designed to address known weaknesses are slow to be adopted because it takes time to test them and overcome the systems issues required to deploy them, and because they frequently end up requiring a net increase in the number of models rather than the replacement of the old model. Despite the known limitations and weakness of the Gaussian copula model, it was widely used without appropriate governance.

Another example of widespread model failures pre-crisis was the disappointing performance of economic capital models used by most large banks in the U.S. and Europe to assess their required capital needs. These models were based on detailed bespoke approaches to assess risks across all activities, on and off balance sheet, of large complex banks, primarily for capital adequacy purposes. Such models were (and still are) typically calibrated to a very low one-year probability of default for the bank, on the order of 0.05%.[6] They became common tools across large complex banks in the 1990s and were widely used in banks' internal assessment of capital adequacy. However, the use of those models emerged just as model validation standards were emerging and since they were viewed as a contributor to "internal" assessments of capital adequacy, they were not subject to standardized, formal supervisory review.

Oliver Wyman (2012) provides a comparison of one-year economic capital estimates from the mid-2000s vs. realized one-year losses in the crisis to demonstrate the inadequacy of the modeled results. Of 16 financial institutions with publicly reported economic capital results, 25% experienced losses of at least 150% of their economic capital estimates (Figure 2).

[6] For a discussion of economic capital models and their use, see Dev (2004).

Figure 2: Ratio of Crisis Losses to Declared Pre-Crisis Economic Capital[7]

16 INSTITUTIONS WITH PUBLICLY STATED ECONOMIC CAPITAL

In the U.S., the worst of the financial crisis came to an end with the 2009 bank stress test, the SCAP (Supervisory Capital Assessment Program) which spawned the post-crisis regulatory stress testing program, now mandated by the Dodd Frank Act. A key component of the SCAP was the use of supervisory models based on detailed bank data, as described in Hirtle, Schuermann and Stiroh (2009). This event marks the beginning of the modern approach to capital regulation, which is characterized by the approval of target capital levels informed by stress test modeling. With the SCAP and subsequent CCAR program which commenced in 2011, risk modeling expanded from just balance sheet exposures to also take into account, formally, income statement dynamics, and did so by explicitly conditioning on economic and market risk factors such as unemployment, GDP, home prices, interest rates and equity indices. All U.S. banks >$10bn in assets are required to run such stress tests using three provided supervisory scenarios at least once a year, and banks >$50bn in assets that are part of the Fed's CCAR program, are also required to design their own stress scenarios suitable for their particular business and risk profile (which may be different from a more generic profile to which the common supervisory scenarios are tailored).

There are over 200 line items in the CCAR forms, the FR Y-14A, which require some type of modeled output. That requires a lot of models! It is not uncommon for a CCAR bank to have developed 50-150 models specifically for their CCAR submissions. These models are now expected to be subjected to a rigorous and formal model risk management program, including but no longer limited to, model validation. All of this is quite resource intensive. Models can

[7] Analysis is based on publicly reported economic capital results within 3 years prior to the start of the crisis and the maximum losses over the worst one-year period, as defined by Bloomberg.

take several months to build, and 4-8 weeks to validate. We see the staffing of model risk management groups approaching the size of the modeling groups themselves.

3. Model risk management today …. and going forward

Over the decade following the issuance of the OCC's Model Validation Guidance in 2000, supervisory attention was broadened from model validation to the more general concept of model risk management. That evolution was reflected in a joint Supervisory Guidance on Model Risk Management issued by the Federal Reserve and the OCC in 2011, which marks the beginning of the phase 3 in the evolution of model risk management.[8] This modern view of model risk management, articulated in the guidance, recognizes that risk is inherent in model use and calls for a risk management framework that is similar to the frameworks used to manage other important risks to the firm.

A sound model risk management framework is predicated on the notion that modeling is a process as opposed to a discrete, one-time activity. Consequently, model risk management reflects the "life-cycle" view of the modeling process, from the initial business or risk management need to development, testing and validation, implementation, monitoring and updating, to its ultimate retirement.

As with all risk management activities, model risk management requires a framework that comprises appropriate infrastructure, management attention and board oversight.[9] The key elements of that framework are:

- An expression of an acceptable degree of model risk as part of the firm's risk appetite statement, and a general level of awareness of and respect for model risk within the firm
- Policy and procedures that assign clear responsibilities, accountabilities and controls
- Senior management demonstration of responsibility and accountability for the framework through the devotion of appropriate resources and attention to model risk and its management
- Board of Directors demonstration of oversight over this risk management framework, commensurate with its importance to the institution.

In summary, the modern view of MRM is much broader than the act of model validation, requiring the recognition that model risk is inherent to the use of models and that the proper management of model risk requires a formal program with numerous potential elements that can be used to minimize or respond to the risk. As an indicator of the professionalization of MRM, a casual survey among our clients in the U.S. (in this case about two dozen large banks

[8] Federal Reserve Board & Office of the Comptroller of the Currency, Supervisory Guidance on Model Risk Management (April 4, 2011).

[9] For a discussion of the Board's responsibilities, see Yoost (2013).

from the CCAR program plus some large foreign banks active in the U.S.) indicates that about half of the heads of model risk management are now direct reports to the Chief Risk Officer, making them peers of heads of market and credit risk management and business risk heads. Chief model risk managers now provide regular reports and direct presentations to the risk committee of Boards of Directors of banks, further evidence of the much elevated stature of MRM following the financial crisis.

This modern view of model risk management, however, is not a completely new invention; instead it reflects the culmination of a view developed over decades. Returning to the 1996 Goldman Sachs Research Note on model risk, for example, Derman noted that there are many types of model risk with an array of appropriate responses. An interesting example was the risk of having the correct model, used inappropriately: "There are always implicit assumptions behind a model and its solution method. But human beings have limited foresight and great imagination, so that, inevitably, a model will be used in ways its creator never intended….The **only practical defense is to have informed and patient users** who clearly comprehend both the model and the method of solution and even more important, understand what can go wrong." (emphasis added); p.7.

As we noted above, an important innovation since the financial crisis has been the development and use of supervisory models, in other words, models developed by regulators, using detailed proprietary bank data (but also public data), whose purpose is to assess capital adequacy of banks. These types of stress testing models have been used as a crisis response tool both in the U.S. and in Europe, but are now being used as a tool for ongoing bank supervision, most especially through the CCAR program (Tarullo, 2014). While the Federal Reserve does not provide any detail of its models, some description is given in Board of Governors (2014) and by Hirtle, Kovner, Vickery and Bhanot (2014) for a complementary set of models based on publicly available bank regulatory reports (the FR Y-9C reports).

With the growing use of models comes the need for model risk management, arguably especially important for regulators since those models, by design, affect not just individual banks but the entire banking system (or at least the roughly 80% subject to the CCAR program), and are thus a nontrivial source of systemic risk. Recognizing this need, the Federal Reserve created a Model Validation Council in 2012, comprised of academics to "provide expert and independent advice on its process to rigorously assess the models used in stress tests of banking institutions".[10]

To summarize, the management of model risk in U.S. banks has improved since it first became a point of emphasis to the industry and to bank regulators two decades ago. Sufficient progress had not been made, however, to avoid being a significant contributor to the Great Financial Crisis. While the attention paid to the management of model risk has accelerated since the crisis, modelling has continued to change, including significant new stress testing modelling efforts by both the banks and the regulators. It is far from clear whether the enhanced model risk management environment is sufficient to control the new risks.

[10] See http://www.federalreserve.gov/aboutthefed/mvc.htm

References

Ashcraft, Adam and Til Schuermann, 2008. "Understanding the Securitization of Subprime Mortgage Credit," *Foundations and Trends in Finance* 2:3, 191-309. A pre-publication version is available as Pre-publication version available as Federal Reserve Bank of New York Staff Report #318.

Basel Committee on Banking Supervision, 1996. "Amendment to the Capital Accord to Incorporate Market Risks (No. 24)", January. Available at http://www.bis.org/publ/bcbs24.htm

Basel Committee on Banking Supervision, 2011. "Basel III: A global regulatory framework for more resilient banks and banking systems," June. Available at http://www.bis.org/publ/bcbs189.htm

Board of Governors of the Federal Reserve System, 2014. *Comprehensive Capital Analysis and Review 2014: Assessment Framework and Results*. Available at http://www.federalreserve.gov/newsevents/press/bcreg/ccar_20140326.pdf

Bollerslev, Tim, 1986. "Generalized Autoregressive Conditional Heteroskedasticity," *Journal of Econometrics*, Vol.31, 307-327.

Brigo, Damiano, Andrea Pallavicini, and Roberto Torresetti, 2010. "Credit Models and the Crisis, or: How I learned to stop worrying and love the CDOs," working paper. An expanded version appeared as *Credit Models and the Crisis: A journey into CDOs, Copulas, Correlations and Dynamic Models*, Wiley, Chichester, 2010.

Derman, Emanuel, 1997. "Model Risk," Goldman Sachs Quantitative Strategies Research Notes, April, p. 7.

Diebold, F.X., 2012. "100+ Years of Financial Risk Measurement and Management," in F.X. Diebold (ed.), *Financial Risk Measurement and Management* (ed.). Cheltenham, U.K. and Northampton, Mass.: Edward Elgar Publishing Ltd. (International Library of Critical Writings in Economics)

Dev, Ashish, 2004. *Economic Capital*, Ashish Dev (editor). London: Risk Books, Incisive Media.

Duffie, Darrell, 2007. "Innovations in Credit Risk Transfer: Implications for Financial Stability," pp. 40-41. July. Available at http://www.darrellduffie.com/uploads/working/DuffieInnovationsCreditRiskTransfer2007.pdf

Engle, Rob, 1982. "Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation," *Econometrica* 50:4, 987-1007.

Federal Reserve Board of Governors, "The Federal Reserve System Purposes & Functions," Ninth Edition, June 2005, pp 59-60. Available at http://www.federalreserve.gov/pf/pdf/pf_complete.pdf

Hirtle, Beverly J., Til Schuermann and Kevin J. Stiroh, 2009. "Macroprudential Supervision of Financial Institutions: Lessons from the SCAP," Federal Reserve Bank of New York Staff Report 409.

Hirtle, Beverly J, Anna Kovner, James Vickery, and Meru Bhanot, 2014. "Assessing Financial Stability: The Capital and Loss Assessment under Stress Scenarios (CLASS) Model," Federal Reserve Bank of New York Staff Report 663.

Jorion, Philippe, 2000. "Risk Management Lessons from Long-Term Capital Management". *European Financial Management* 6, September, 277-300.

Jorion, Philippe, 2006. *Value at Risk*. New York: McGraw Hill.

Oliver Wyman, 2012. "Strategic Capital: Defining an Effective Real-World View of Capital." Available at http://www.oliverwyman.com/insights/publications/2012/aug/strategic-capital--defining-an-effective-real-world-view-of-capi.html

Salmon, Felix, 2009. "Recipe for Disaster: The Formula That Killed Wall Street," *Wired* 17.03, Feb 23.

Tarullo, Daniel K., 2014. "Stress Testing after Five Years," speech given at the Federal Reserve Third Annual Stress Test Modeling Symposium, Boston, MA. Available at http://www.federalreserve.gov/newsevents/speech/tarullo20140625a.htm

Yoost, Dean, 2013. "Board Oversight of Model Risk Is a Challenging Imperative," *The RMA Journal*, November, 24-30.