The Feasibility of Systemic Risk Measurement

Written Testimony of Andrew W. Lo*

Prepared for the U.S. House of Representatives

Financial Services Committee

October 19, 2009

Chairman Frank, Ranking Member Bachus, and other members of the House Financial Services Committee, I would like to start by thanking you for giving me an opportunity to submit this written testimony regarding the feasibility of systemic risk measurement. In the interest of full disclosure, I wish to inform the committee that I am a principal investigator in a project funded by the National Science Foundation, and in addition to my academic position at MIT, I am affiliated with an asset management company that manages several hedge funds and mutual funds.

I believe that establishing the means to measure and monitor systemic risk on an ongoing basis is the single-highest priority for financial regulatory reform, and am grateful for the Committee's interest in this issue.

Even the most cautious policymaker would agree that attempting to eliminate all systemic risk is neither feasible nor desirable—risk is a necessary ingredient to real economic growth. Moreover, individual financial institutions do not have the means or the motivation to address systemic risk themselves. In competing for market share and revenues, each entity will typically take on as much risk as its shareholders will allow, without considering the consequences for the financial system as a whole. In much the same way that manufacturing companies did not consider their impact on the environment prior to pollution regulation, we cannot fault financial institutions for ignoring the systemic implications of their risk-taking in the absence of comprehensive risk regulation. Unless we are able to measure systemic risk objectively, quantitatively, and regularly, it is impossible to determine the appropriate trade-off between such risk and its rewards and, from a policy perspective and social welfare objective, how best to contain it. This is the current challenge that faces the House Financial Services Committee.

Before turning to the substance of my testimony, parts of which are drawn from my previous testimony to the House Oversight Committee (Lo, 2008b), I would like to summarize four of the most important themes here:

---

*Harris & Harris Group Professor, MIT Sloan School of Management, and Chief Investment Strategist, AlphaSimplex Group, LLC. Please direct all correspondence to: Andrew W. Lo, MIT Sloan School of Management, 50 Memorial Drive, E52–454, Cambridge, MA 02142. I am grateful to Tobias Adrian, Morten Bech, Claudio Borio, Jerry Chafkin, Phil Cooper, Arnout Eikeboom, Jacob Goldfield, Brenda Gonzalez-Hermosillo, Dale Gray, Jerrold Grochow, Joseph Haubrich, Greg Hayt, Andreas Jobst, Dennis Kass, Paul Kukuruza, Deborah Lucas, Saman Majd, Marc Menchel, Robert Merton, Eric Rosenfeld, Manmohan Singh, Kimmo Soramäki, Donald Sussman, Phil Vasan, and Ernest Zhu for helpful comments and discussion, and I thank AlphaSimplex and the MIT Laboratory for Financial Engineering for research support.

1. Before we can hope to reduce the risks of financial crises, we must be able to define and measure those risks explicitly. Therefore, a pre-requisite for effective financial regulatory reform is to develop dedicated infrastructure for defining, measuring, monitoring, and investigating systemic risk on a standardized, ongoing, and regular basis.
2. Systemic risk measurement and regulation will likely require new legislation compelling systemically important entities to provide more transparency on a confidential basis to regulators, e.g., information regarding their assets, liabilities, holdings, leverage, collateral, liquidity, counterparties, and aggregate exposures to key financial variables and other risks. These requirements are much less intrusive than position transparency—which is both impractical and unnecessary for purposes of systemic risk regulation—and should already be available from any systemically important entity's enterprise risk management system.
3. The infrastructure required to collect, clean, analyze, organize, and store this data in a secure and robust fashion will be substantial, but this is true for any worthwhile national-level data-rich undertaking such as the Bureau of Economic Analysis, the Bureau of Labor Statistics, and the National Weather Service. Given the complexity and importance of the financial system to real economic growth—and the recessionary impact that systemic events can have on the real economy—measuring systemic risk is arguably as vital to our national interest as measuring economic productivity and weather patterns. This data-collection effort can be expedited by leveraging existing organizations and data sources including the CFTC, DTCC, Federal Reserve, FDIC, FINRA, NFA, OCC, OTS, SEC, and the credit bureaus and credit-rating agencies.
4. Because systemic risk cuts across multiple regulatory bodies that do not necessarily share the same objectives and constraints, it may be more efficient to create an independent agency patterned after the National Transportation Safety Board (NTSB), solely devoted to measuring, tracking, and investigating systemic risk events in support of—not in competition with—all regulatory agencies. In addition to managing the data and research infrastructure described above, this agency would also be staffed by full-time and "virtual" teams of expert and experienced forensic accountants, lawyers, economists, and financial engineers who sift through the wreckage of every major financial blow-up, collect the "black boxes", and produce publicly available reports with their findings and recommendations. Like the NTSB, this agency would assist the appropriate regulators by establishing regular lines of communication with the media as financial crises unfold to manage the flow of information and reduce the likelihood of panic, which is one of the main catalysts of crisis and much easier to prevent than they are to extinguish once ignited.

I would like to add two caveats to the discussion that follows. The first is that while the need for regulatory reform may seem clear in light of the current financial crisis, the underlying causes are complex, multi-faceted, and not yet completely understood. Therefore, I would urge the Committee and other parts of government to refrain from reacting too hastily to market events, but to deliberate thoughtfully and broadly to craft new regulations for the financial system of the 21st century. We do not need more regulation; we need more effective regulation.

Second, since this testimony will become part of the public record, I wish to emphasize that this document is not a formal academic research study, but is a summary of some of the policy implications that I have drawn from my interpretation of such research, and is intended for a broader audience of policymakers and regulators.

Measures of Systemic Risk

The well-known adage that "one cannot manage what one cannot measure" is particularly relevant for the notion of *systemic risk*, a term that has come into common usage but which does not yet have a standardized definition or a universally accepted method for gauging its magnitude. Systemic risk is usually taken to mean the risk of a broad-based breakdown in the financial system, often realized as a series of correlated defaults among financial institutions—typically banks—that occurs over a short period of time, i.e., a "bank run" that spreads quickly and leads to multiple bank failures. The events of 2007–2009 have taught us that runs can affect non-bank entities as well, such as money market funds, insurance companies, hedge funds, government-sponsored enterprises, and broker/dealers. Moreover, in a recent study commissioned by the G-20, the IMF determined that systemically important institutions are not limited to those that are the largest, but also includes others that are interconnected and that can impair the normal functioning of financial markets, including the provision of credit to households.[1]

The starting point for regulatory reform is to develop formal measures of systemic risk, measures that capture the linkages and vulnerabilities of the entire financial system—not just those of the banking industry—and with which we can monitor and regulate the overall level of risk to the system and its interconnectedness to the real economy. Given the complexity of the global financial system, it is unrealistic to expect that a single measure will suffice. For example, in a recent study on systemic risk in the U.S. residential housing market, it is shown that systemic events can arise from the simultaneous occurrence of three trends: rising home prices, falling interest rates, and increasing efficiency and availability of refinancing opportunities.[2] Individually, each of these trends is benign, and often considered bellwethers of economic growth. But when they occur at the same time, they inadvertently cause homeowners to synchronize their equity withdrawals via refinancing, ratcheting up homeowner leverage simultaneously without any means for reducing leverage when home prices eventually fall, ultimately leading to waves of correlated defaults and foreclosures. While excessive risk-taking, overly aggressive lending practices, pro-cyclical regulations, and government policies may have contributed to the recent problems in the U.S. housing market, this study shows that even if all homeowners, lenders, investors, insurers, rating agencies, regulators, and policymakers behaved rationally, ethically, and with the purest of intentions, financial crises can still occur.

Given its complexity, monitoring systemic risk requires better data collection and a variety of measures that capture the following seven broad characteristics of the entire financial system: (1) leverage; (2) liquidity; (3) correlation; (4) concentration; (5) sensitivities; (6) implicit guarantees; and (7) connectedness.

Leverage refers to the ability to invest amounts larger than one's capital base by borrowing, and liquidity refers to the ease and speed with which funds can be raised or investments can be liquidated. The mechanisms by which these two characteristics combine to produce systemic risk are now well understood. Because many financial institutions make use of leverage, their positions are often considerably larger than the amount of collateral posted to support those positions. Leverage has the effect of a magnifying glass, expanding small profit opportunities into larger ones, but also expanding small losses into larger losses. And when unexpected

[1] See IMF (2009a).
[2] See Khandani, Lo, and Merton (2009).

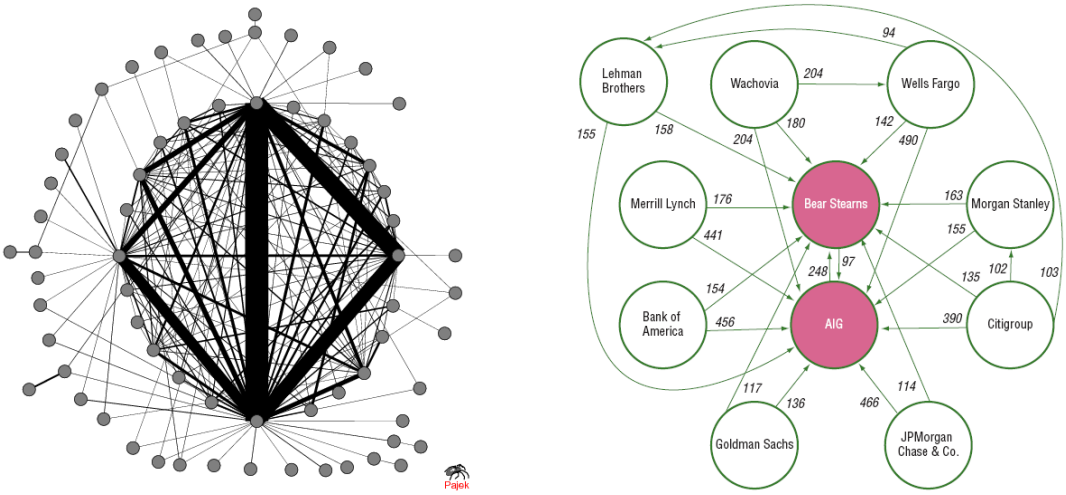
adverse market conditions reduce the value of that collateral, such events often trigger forced liquidations of large positions over short periods of time to reduce leverage, which can lead to systemic events as we have witnessed over the past two years. In particular, the more illiquid the positions, the larger the price impact of forced liquidations, leading to a series of insolvencies and defaults and, ultimately, increased unemployment and recession as financial institutions deleverage. This is systemic risk. Of course, the likelihood of a major dislocation also depends on the degree of correlation among the holdings of financial institutions, how sensitive they are to changes in market prices and economic conditions, how concentrated the risks are among those financial institutions, whether there are any implicit guarantees that promote excessive risk-taking behavior, and how closely connected those institutions are with each other and the rest of the economy.

By looking at the financial system as if it were a single portfolio, several useful measures of systemic risk can be derived from existing financial models. For example the well-known framework of contingent claims analysis can be applied to the macroeconomy, which yields several potentially valuable early warning indicators of systemic risk that include aggregate asset-liability mismatches, nonlinearities in the risk/return profile of the financial sector, implicit government guarantees, and default probabilities for various types of sovereign debt.[3] Illiquidity and "crowded trades" can be measured using various statistical tools and simulation techniques, and aggregate measures can be derived by combining the results from individual sectors and corporations.[4] Sensitivities, correlations, and concentration risks can also capture important aspects of systemic risk,[5] and it is worth noting that some of these measures did provide early warning signs of potential dislocation in the financial industry from 2004 to 2006.[6]

But the increased complexity and connectedness of financial markets is a relatively new phenomenon that requires a fundamental shift in our linear mode of thinking with respect to risk measurement. Small perturbations in one part of the financial system can now have surprisingly large effects on other, seemingly unrelated, parts of that system. These effects have been popularized as so-called "Black Swan" events—outliers that are impossible to predict—but they have more prosaic origins: they are the result of new connections between sectors and events that did not exist a decade ago, thanks to financial innovation, increased competition, and technological progress.[7] In fact, a more accurate rendition of "too big to fail" is "too connected to fail", and with the proper information, we can identify black swans while they are still cygnets. For example, a network map of the Fedwire inter-bank payment system (Figure 1a) has yielded a number of new insights about the risk exposures of this important network, including a current snapshot of where the most significant vulnerabilities are concentrated, and the IMF's (2009) conditional credit risk estimates for major U.S. financial institutions for March 2008

[3] See Bodie, Gray, and Merton (2007), Gray and Malone (2008), and Gray.
[4] See Getmansky, Lo, and Makarov (2004), Khandani and Lo (2007, 2008), and Khandani, Lo, and Merton (2009).
[5] See Acharya and Richardson (2009), Adrian and Brunnermeier (2008), Chan et al. (2006, 2007), Gray (2009), Huang, Zhou, and Zhu (2009), IMF (2009b), Lo (2008a), and Rajan (2006).
[6] For example, see Gimein (2005) and Rajan (2006).
[7] One example is apparent correlation among quantitative equity market neutral managers that led to the Quant Meltdown of August 2007 (see, for example, Khandani and Lo, 2007, 2008, and Rothman, 2007a,b). See Singh and Aitken (2009) for an analysis of counterparty risk, which is another manifestation of connectedness.

(Figure 1b) highlighted AIG, Bear Stearns, and Lehman as institutions with particularly significant exposures.[8]



(a) (b)

Figure 1. (a) Core of the Fedwire Interbank Payment Network, from Soramäki et al. (2007, Figure 2); and (b) conditional co-risk measures among major U.S. financial institutions for March 2008, from IMF (2009, Figure 2.6).

However, while many tools exist for measuring systemic risk, these measures have, at best, yielded indirect indications of the build-up of systemic risk over the last few years because regulators lack the necessary data to generate definitive, timely, and actionable measures. Imagine deciding on fiscal stimulus policies in the absence of GDP and unemployment figures over the last few quarters, or formulating environmental protection policies without ecological impact estimates of urban development. The required inputs to systemic risk measures are dispersed across many institutions, jurisdictions, and information-technology platforms, and a significant portion of this data is private. Moreover, a private-sector solution to measuring systemic is unlikely to emerge because, like national defense, environmental protection, and public works, systemic risk may affect everyone but no individual entity has the ability, the information, or the incentive to manage it properly. It will take an act of Congress to create the required infrastructure, and this is the task facing the House Financial Services Committee.

Data Requirements

The quality and management of relevant data from bank and non-bank financial institutions is an integral part of decoding impending systemic risks. While banks and other regulated financial institutions provide certain information to their regulators, not all systemically important entities are covered, and those that are may not be required to provide the kind of information most relevant for systemic risk monitoring and regulation. For example, hedge funds registered with the U.S. Securities Exchange Commission under the Investment Advisers Act of 1940 are not

[8] See Soramäki et al. (2007). Recent advances in the mathematical theory of networks, e.g., Watts and Strogatz (1998) and Watts (1999), may be particularly relevant for analyzing such vulnerabilities in the financial system.

required to disclose the amount of leverage they employ, the nature of their holdings, or the identities of their credit counterparties. The insurance industry is regulated only at the state level, hence there is currently no formal disclosure of information by insurance companies to federal regulators. Even the highly regulated banking industry's information flows are not ideally suited for systemic risk transparency, with some banks reporting state regulators, others to the FDIC, many to the Office of the Comptroller of the Currency, and the state-member banks and bank holding companies reporting to the Federal Reserve.

Without access to the appropriate data, systemic risk cannot be measured accurately. For the same reason that national income accounts are a pre-requisite to formulating sound fiscal policies, the first and most significant step in the process of financial regulatory reform is to require all systemically important entities—including banks, bank holding companies, hedge funds, mutual funds, insurance companies, broker/dealers, mortgage lenders, government-sponsored enterprises, exchanges, ECNs, and others—to provide regulators with the necessary inputs for measuring systemic risk. This will likely include the following information on a regular (at least monthly), timely, and strictly confidential and anonymized basis:[9]

- Assets and liabilities (on- and off-balance-sheet, marked to market)
- Leverage and contractual terms
- Aggregated portfolio holdings, including OTC derivatives and contractual terms
- Current list of significant shareholders, investors, counterparties, and bilateral exposures
- Portfolio sensitivities to changes in major market indexes and other scenarios

The last item requires further explanation. For the most complex and illiquid securities—which also happen to be among the most relevant securities for systemic risk—it will be virtually impossible for any third party to value them. However, it is a simple matter to require owners of those securities to provide, on an aggregate basis, estimates of their losses or gains in response to, say, a 5% increase in crude oil prices, a 25-basis-point decline in the Fed Funds rate, or a 10% drop in the S&P 500. By asking all systemically important entities to provide such sensitivities for a pre-specified set of scenarios, and also by inviting these entities to propose their own scenarios, regulators need not analyze position-level data, nor do they need to develop pricing models for universe of assets held by financial institutions. These sensitivities can then be aggregated across institutions to yield systemic scenario analyses. If such aggregate scenarios were available in 2006, they would likely have shown the enormous build-up of systemic risk in the U.S. housing market and its derivatives.

These data requirements may seem onerous, but they are less exacting than the inputs of any systemically important financial institution's existing enterprise-wide risk management system. A side benefit of imposing such requirements is that whether or not a financial institution can provide such data may be a useful screening mechanism to identify institutions with potentially inadequate risk controls, which, for systemically important entities, poses systemic risk in its own right. Also, for purposes of systemic risk measurement, aggregated values are sufficient for many of the required data items, eliminating the need for large amounts of data at the individual-transaction level. After all, by definition, only the most significant aggregate exposures will be relevant to systemic risk measurement. However, there is no disputing that these new reporting

[9] Borio and Drehmann (2009) and Johnston et al. (2009) provide a more complete account of the "information gap" identified by the recent financial crisis and how systemic risk measurement may be accomplished.

requirements for systemically important entities will be costly—this may be an unavoidable consequence of building a more robust financial system.

Of course, the regulatory need for risk transparency must be balanced against the necessity of preserving the intellectual property that financial institutions possess. Unlike other technology-based industries, the vast majority of financial innovations are protected through trade secrecy, not patents.[10] For example, hedge funds are among the most secretive of financial institutions because their franchise value is almost entirely based on the performance of their investment strategies, and this type of intellectual property is perhaps the most difficult to patent. Therefore, such entities have an affirmative obligation to their investors to protect the confidentiality of their investment products and processes. If forced to reveal their strategies, the most intellectually innovative entities will simply cease to exist or move to other less intrusive regulatory jurisdictions. This would be a major loss to U.S. capital markets and our economy, hence it is imperative that policymakers tread carefully with respect to this issue and coordinate with foreign regulators. But several government agencies such as the Federal Reserve, OCC, NSA, and SEC already handle highly confidential information with reasonable success, so the public sector does have the capability of managing sensitive financial data.

Implementation Issues

Collecting, cleaning, integrating, archiving, analyzing, monitoring, and securely storing such data is, of course, a significant technological undertaking, and may require the establishment of a new government agency dedicated solely to this function. Although several regulators such as the CFTC, FDIC, Federal Reserve, OCC, OTS, and the SEC already collect data related to systemic risk, they do not necessarily share the same regulatory objectives, constraints, and institutional purview. Also, the global nature of financial markets and institutions implies that the regulatory landscape is even more complex, with competing agendas and objectives of foreign regulators such as the BIS, ECB, and FSA. While the existing regulatory bodies have overlapping perspectives, they are neither redundant nor all-encompassing, hence a new agency focused solely on systemic risk measurement will serve a different and useful purpose. This option does not seem so radical in light of the fact that a well-functioning financial system is critical to general economic growth and stability. The complexities of today's financial system require more focused resources to fully comprehend and regulate its risks.

A significant portion of the data-collection process can be expedited by leveraging existing data sources and technologies such as those of the CFTC, DTCC, Federal Reserve, FDIC, FINRA, NFA, OCC, OTS, SEC, and credit bureaus and credit-rating agencies. Having one single agency responsible for this data will greatly streamline its collection, maintenance, and analysis. Once populated, this systemic-risk database will serve as a general utility for all regulatory agencies, yielding potentially significant cost savings by allowing other agencies to outsource some or all of their data-collection and maintenance functions to this organization. Also, by charging this new agency with the ongoing responsibility of creating high-level risk analytics such as a network map of the financial system, estimates of illiquidity exposure, concentration, and excessive leverage, and publicizing redacted and aggregate indicators of systemic risk, we will enhance the self-correcting tendencies of the private sector while helping regulators and the public better prepare for systemic events. Although the initial set-up cost is likely to be

[10] See Lerner (2002) for a discussion of financial patents.

significant, this amount pales in comparison to the potential savings that an effective financial "early warning system" for monitoring systemic risk can generate for taxpayers. One proposal is to defray these costs by asking producers of systemic risk to underwrite them through a "systemic risk capacity charge" (assuming that a standardized metric of systemic risk can be constructed), in much the same way that the environmental impact of industrial activities is regulated through pollution rights and taxes.[11]

It should be emphasized that systemic risk measurement and monitoring is distinct from systemic risk regulation. The latter function is already being served to differing degrees by regulators such as the CFTC, FDIC, Federal Reserve, OCC, OTS, and SEC for their respective sectors of the financial industry, and there are some compelling arguments for maintaining decentralized regulatory authority across agencies with specialized mandates and skills. Whether or not these agencies require greater powers and broader mandates, or if they should be combined to yield a smaller number of regulators, or if we need an entirely new systemic-risk regulator are questions that require thoughtful deliberation and may not be resolved quickly. But regardless of how the regulatory responsibilities for the financial system are ultimately divvied up, all parties should be able to agree on the need to develop reliable, timely, and regular measures of systemic risk.

This separation of measurement and regulation is, in fact, the model for the National Transportation Safety Board (NTSB), an independent government agency focused on promoting transportation safety through forensic investigations of airplane crashes and other accidents, and maintaining a public searchable database of their accident reports. The NTSB has no regulatory authority (in particular, the FAA regulates the airline industry), but through its authoritative analyses of literally thousands of crashes and near misses, the NTSB has had a significant impact on air safety as well as the growth of the airline industry. Financial crashes are, of course, considerably less dire, generally involving no loss of life. However, the current financial crisis, and the eventual cost of the Fannie Mae, Freddie Mac, and TARP rescue packages, should be sufficient motivation to create a "Capital Markets Safety Board" (CMSB) dedicated to investigating, reporting, and archiving the "accidents" of the financial industry.

By maintaining "virtual" teams of experienced professionals—forensic accountants, lawyers, economists, and financial engineers from industry and academia, and securities and tax attorneys—that are "on demand" and work together on a regular basis over the course of many cases to investigate every single financial disaster, a number of new insights, common threads, and key issues would emerge from their analysis. The publicly available reports from the CMSB would yield invaluable insights to individuals and institutions seeking to protect their investments and organizations from similar fates, eventually driving the financial industry (and their regulators) to improve their "safety record".[12] Like the NTSB, the CMSB would also assist

[11] See Acharya et al. (2009). Tarashev, Borio, and Tsatsaronis (2009) propose an elegant method for apportioning such charges among those institutions deemed to be systemically important.

[12] Of course, formal government investigations of major financial events do occur from time to time, as in the April 1999 *Report of the President's Working Group in Financial Markets on Hedge Funds, Leverage, and the Lessons of Long-Term Capital Management*. However, this inter-agency report was put together on an ad hoc basis with committee members that had not worked together previously and regularly on forensic investigations of this kind. With multiple agencies involved, and none in charge of the investigation, conclusions and recommendations must be reached by consensus, which may reduce the scope and impact of the analysis. Although any thorough investigation of the financial services sector must involve the SEC, the OCC, the CFTC, the U.S. Treasury, and the Federal Reserve, there are important operational advantages in tasking a single office with the responsibility for leading such

the appropriate regulators as crises unfold by establishing regular lines of communication with the media to manage the flow of information and reduce the likelihood of panic, which is one of the main catalysts of crisis and much easier to prevent than they are to extinguish once ignited.

Perhaps the most significant feature of the NTSB model is its independence, which has, on occasion pitted the NTSB against the FAA. Far from being dysfunctional, this tension has benefitted the public through the natural checks and balances that NTSB investigations and recommendations have had on regulatory behavior. Regulators are human, and therefore subject to the same psychological influences that generated irrational exuberance among homeowners, investors, mortgage lenders, broker/dealers, and policymakers during the housing boom. An independent CMSB providing data, analysis, and monitoring of various potential systemic events—with no agenda other than to generate the most accurate risk measures and forecasts—may serve as a useful and objective point of reference, even for regulatory bodies that have their own analytical capabilities.[13]

The establishment of a CMSB will not be inexpensive. The lure of the private sector poses a formidable challenge to government agencies to attract and retain individuals with expertise in these highly employable fields. Individuals trained in forensic accounting, financial engineering, and securities law now command substantial premiums on Wall Street over government pay scales, even in the aftermath of the recent crisis. Although the typical government employee is likely to be motivated more by civic duty than financial gain, it would be unrealistic to build an organization on altruism alone. However, the cost of a CMSB is trivial in comparison to the losses that it may prevent. If regulators had fully appreciated the impact of the demise of Lehman Brothers—which a fully operational CMSB with the proper network map would likely have been able to forecast—the savings from this one incident would likely be sufficient to fund the CMSB for half a century. Moreover, the benefits provided by the CMSB would accrue not only to the wealthy, but would also flow to pension funds, mutual funds, and individual investors in the form of more stable financial markets, greater liquidity, reduced borrowing and lending costs as a result of decreased systemic risk exposures, and a wider variety of investment choices available to a larger segment of the population because of increased transparency, oversight, and ultimately, financial stability.

As long as human behavior is coupled with free enterprise, it is unrealistic to expect that market crashes, manias, panics, collapses, and fraud will ever be completely eliminated from our capital markets, but we should avoid compounding our mistakes by failing to learn from them. Fortunately, systemic events in the United States have been rare. But the magnitude of their consequences for employment, wages, and economic growth is so large that we can no longer afford to ignore them.

---

investigations and serving as a repository for the expertise in conducting forensic examinations of financial incidents.

[13] For example, during the period from 2000 to 2003 when the Fed was cutting interest rates in an attempt to stave off a recession, its research department was no doubt aware of the potential impact on asset prices and aggregate leverage, but the focus of the organization was on stimulating the economy, not on managing systemic risk. In contrast, the SEC—which recently created a new Division of Risk, Strategy, and Innovation, significantly enhancing its ability to analyze and address a broader range of risks—is focused on investor protection, maintaining fair and orderly markets, and facilitating capital formation, not on regulating systemic risk. While both agencies have overlapping responsibilities that involve systemic risk, their different regulatory mandates imply different research agendas and analytical capabilities that the CMSB would complement and reinforce.

References

Acharya, V., Pedersen, L., Philippon, T. and M. Richardson, 2009, "Regulating Systemic Risk", in V. Acharya and M. Richardson, eds., *Restoring Financial Stability: How to Repair a Failed System*, Chapter 13. New York: John Wiley & Sons.

Acharya, V. and M. Richardson, eds., 2009, *Restoring Financial Stability: How to Repair a Failed System*. New York: John Wiley & Sons.

Adrian, T. and M. Brunnermeier, 2008, "CoVaR", Federal Reserve Bank of New York Working Paper No. 348.

Bech, M., Chapman, J., and R. Garratt, 2009, "Which Bank Is the "Central" Bank? An Application of Markov Theory to the Canadian Large Value Transfer System", Federal Reserve Bank of New York Staff Report #356.

Bodie, Z., Gray, D., and R. Merton, 2007, "New Framework for Measuring and Managing Macrofinancial Risk and Financial Stability", NBER Working Paper No. W13607.

Borio, C. and M. Drehmann, 2009, "Towards an Operational Framework for Financial Stability: 'Fuzzy' Measurement and its Consequences", BIS Working Papers No. 284.

Chan, N., Getmansky, M., Haas, S., and A. Lo, 2004, "Systemic Risk and Hedge Funds", Conference Paper, *NBER Conference on the Risks of Financial Institutions*, Woodstock, VT, October 22–23.

Chan, N., Getmansky, M., Haas, S., and A. Lo, 2006, "Do Hedge Funds Increase Systemic Risk?", *Federal Reserve Bank of Atlanta Economic Review* Q4, 49–80.

Chan, N., Getmansky, M., Haas, S., and A. Lo, 2007, "Systemic Risk and Hedge Funds", in M. Carey and R. Stulz, eds., *The Risks of Financial Institutions*. Chicago, IL: University of Chicago Press.

Getmansky, M., Lo, A. and I. Makarov, 2004, "An Econometric Analysis of Serial Correlation and Illiquidity in Hedge-Fund Returns", *Journal of Financial Economics* 74, 529–609.

Getmansky, M., Lo, A., and S. Mei, 2004, "Sifting Through the Wreckage: Lessons from Recent Hedge-Fund Liquidations", *Journal of Investment Management* 2, 6–38.

Gimein, M., 2005, "Is a Hedge Fund Shakeout Coming Soon?", *New York Times*, Sunday, September 4.

Gray, D., 2009, "Modeling Financial Crises and Sovereign Risks", to appear in *Annual Review of Financial Economics* 1.

Gray, D. and S. Malone, 2008, *Macrofinancial Risk Analysis*. New York: John Wiley & Sons.

Huang, X., Zhou, H. and H. Zhu, 2009, "A Framework for Assessing the Systemic Risk of Major Financial institutions", to appear in *Journal of Banking and Finance*.

International Monetary Fund, 2009a, *Systemically Important Institutions, Markets and Instruments* (October 2009). Washington, DC: International Monetary Fund.

International Monetary Fund, 2009b, *Global Financial Stability Report: Responding to the Financial Crisis and Measuring Systemic Risks* (April). Washington, DC: International Monetary Fund.

Johnston, B., Psalida, E., de Imus, P., Gobat, J., Goswami, M., Mulder, C., and F. Vazquez, 2009, "Addressing Information Gaps", IMF Staff Position Note SPN/09/06.

Khandani, A. and A. Lo, 2007, "What Happened to the Quants in August 2007?", *Journal of Investment Management* 5, 5–54.

Khandani, A. and A. Lo, 2008, "What Happened to the Quants in August 2007?: Evidence from Factors and Transactions Data", NBER Working Paper No. 14465.

Lerner, J., 2002, "Where Does *State Street* Lead? A First Look at Finance Patents, 1971–2000", *Journal of Finance* 57, 901–930.

Lo, A., 2008a, *Hedge Funds: An Analytic Perspective*. Princeton, NJ: Princeton University Press.

Lo, A., 2008b, "Hedge Funds, Systemic Risk, and the Financial Crisis of 2007–2008: Written Testimony for the House Oversight Committee Hearing on Hedge Funds (November 13, 2008)", Available at SSRN: http://ssrn.com/abstract=1301217.

Rajan, R. , 2006, "Has Finance Made the World Riskier?", *European Financial Management* 12, 499–533.

Rothman, M., 2007a, "Turbulent Times in Quant Land", U.S. Equity Quantitative Strategies, Lehman Brothers Research.

Rothman, M., 2007b, "View from QuantLand: Where Do We Go Now?", U.S. Equity Quantitative Strategies, Lehman Brothers Research.

Singh, M. and J. Aitken, 2009, "Counterparty Risk, Impact on Collateral Flows and Role for Central Counterparties", IMF Working Paper WP/09/173.

Soramäki, K., Bech, M., Arnold, J., Glass, R. and W. Beyeler, 2007, "The Topology of Interbank Payment Flows", *Physica A* 379, 317–333.

Tarashev, N., Borio, C. and K. Tsatsaronis, 2009, "The Systemic Importance of Financial Institutions", *BIS Quarterly Review* (September), 75–87.

Watts, D., 1999, *Small Worlds: The Dynamics of Networks between Order and Randomness*. Princeton, NJ: Princeton University Press.

Watts, D. and S. Strogatz, 1998, "Collective Dynamics of 'Small-World' Networks", *Nature* 393, 440–442.