Part 1: Introduction

The stability of the financial system and the potential for systemic events to alter its functioning have long been critical issues for central bankers and researchers. Developments such as securitization and greater tradability of financial instruments, the rise in industry consolidation, growing cross-border financial activity, terrorist threats, and a higher dependence on computer technologies underscore the importance of this research area. Recent events, however, such as the terrorist attacks of September 11, 2001, and the collapse of the hedge fund Long-Term Capital Management (LTCM), suggest that older models of systemic shocks in the financial system may no longer fully capture the possible channels of propagation and feedback arising from major disturbances. Nor can existing models account entirely for the increasing complexity of the financial system, the spectrum of financial and information flows, or the endogenous behavior of different agents in the system. Fresh thinking on systemic risk is therefore required.

With that goal in mind, in May 2006 the National Academy of Sciences and the Federal Reserve Bank of New York convened a conference in New York to promote a better understanding of systemic risk. The sessions brought together a broad group of scientists, engineers, economists, and financial market practitioners to engage in a cross-disciplinary examination of systemic risk that could yield insights from the natural and physical sciences useful to researchers in economics and finance.[1] Accordingly, presenters from the natural and mathematical sciences and the engineering disciplines provided examples of tools and techniques used to study systemic collapse in interactive systems in nature and engineering. Similarly, research economists presented studies of systemic risk in cross-border investments, liquidity risk, and the payments system. To provide a context for the discussions, risk managers at large finance institutions described how systemic risk and shocks in the financial system affect trading activities.

[1]The conference program can be found in Appendix A.

Transitioning from a Bank-Based to a Market-Based Financial System

Financial market practitioners began the conference by highlighting various aspects of systemic risk and systemic events in the financial system. The topics of the presentations ranged from historical systemic episodes, such as the liquidity crisis of 1998 and the failure of LTCM, to risk assessment techniques, such as value-at-risk (VaR) analysis and scenario analysis. Charles Lucas of AIG (since retired), a member of the National Academy's Board on Mathematical Sciences and Their Applications, introduced the first session by asking the fundamental question: What is systemic risk?

According to Lucas, economists' theoretical understanding of systemic risk stemmed from the experience of the Great Depression and specifically from John Maynard Keynes's interpretation of that experience in *General Theory of Employment, Interest, and Money*. Keynes aimed the formulation of his "general theory" at capturing the dynamics that allowed an economy to transition to an inferior but stable equilibrium, in the process overturning the normal full-employment equilibrium that defined classical models. During the Great Depression, the economy underwent a shock that was sustained by sympathetic movements throughout the financial system—a sequence of events that has come to be called "contagion." Because of policy missteps and a feedback loop with the financial system, the real economy settled into a persistent state of underutilized resources and unemployment. Despite structural changes since that time, the idea of a feedback loop between the financial and real sectors of the economy that leads to an inferior equilibrium with negative consequences for the real economy remains pertinent to current analysis of financial stability.

That system has changed dramatically since the Great Depression, as described in the conference background paper on the evolution of systemic risk.[2] Though banks still play a large role, many functions that defined their traditional domain are increasingly performed by securities

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markets and nonbank market participants. For example, hedge funds, private equity groups, and other fund managers now control larger shares of financial capital and take active roles in asset and credit markets. Crises in this more market-based financial system, such as the stock market crash of October 1987 and the market liquidity crisis of 1998, fit a general pattern of rapid decline in the price of some asset or class of assets, leading to a drop in liquidity. The result is contagion, in the form of further sympathetic price declines and a shift in market conditions marked by severely reduced financial market activity and potential negative effects on the real economy. Likewise, although the linkage mechanisms may have changed completely since the Great Depression, and despite the skepticism Keynes's theory received from the research community at the time, this simple model captures the mechanisms underlying the Depression. The endogenous shock in the United States that led to the inferior equilibrium then was a stock market crash followed by a wave of bank runs and loss of liquidity in a feedback mechanism of self-fulfilling prophecy. As Lucas suggested, this comparison offers a basic historical analogy illuminating some of the modern phenomena of systemic risks, such as sudden "regime shifts" in the financial system and the role of feedback mechanisms.

The conference background paper by Hendricks, Kambhu, and Mosser also describes the now well-studied phenomenon of the "bank run." In the classical model, a commercial bank makes illiquid loans on the asset side of its balance sheet, and takes demand deposits on the liabilities side that it is obligated to pay back at any time. In a bank run, even though each depositor would be willing to leave his or her funds on deposit, the belief that other depositors are likely to withdraw theirs causes all rational depositors to try to withdraw their funds as quickly as possible. A run on the bank results, because the bank's loans cannot be liquidated immediately at their full value, leaving the bank with no funds for the last depositors in line. In such a scenario, a run can be triggered by concerns about liquidity even if the bank is otherwise solvent.

Moreover, in this model, self-fulfilling prophecies can make bank runs contagious: If depositors witness a run on one bank, they may believe that runs are more likely to occur on others. This scenario can be attributed to several factors. For example, the issue that sparked a run on one bank, such as excessive loan exposure to real estate or the oil industry, may be perceived to affect other banks, or one or more other banks may have significant interbank exposures to the affected institution.

As the Great Depression revealed, the withdrawal of funding liquidity resulting from bank runs can accentuate economic downturns and generally influence the real economy as lending is curtailed to creditworthy entities.[3] Thus, the primary policy approaches to managing financial instability in a bank-oriented financial system—lender-of-last-resort facilities by the central bank, deposit insurance, and banking supervision to ensure credit quality in loan portfolios—were all aimed at preventing or mitigating the effects of these potentially catastrophic withdrawals of funding liquidity from the system. As the relative importance of banks as financial intermediaries has declined with the growth of market-based financial intermediation, market-based systemic events such as the stock market crash of 1987 and the failure of LTCM have shifted the emphasis from *funding liquidity* to *market liquidity*. Moreover, as

[2]"Systemic Risk and the Financial System," by Darryll Hendricks, John Kambhu, and Patricia Mosser; the paper can be found in Appendix B of this volume.

[3]See the conference background paper described in footnote 2.

Federal Reserve Board Governor Donald L. Kohn observed, the Federal Reserve is midway through a long process of adapting its policy tools to this new environment.[4]

As Hendricks, Kambhu, and Mosser describe in their conference background paper (Appendix B of this volume), the shift from a financial system dominated by banks to one dominated by markets has as its hallmark a broadening of the types of activities that banks and other financial intermediaries engage in and the assets that they invest in. The large financial institutions at the core of the system now intermediate the movement of capital in many ways: They assist businesses in the issuance of new stocks and bonds directly to the market (investment banking), they intermediate secondary-market trading of stocks and bonds after issuance on behalf of clients (market making), they lend directly to households and businesses (traditional commercial banking), and they manage asset portfolios on behalf of individuals and institutions (asset management). This latter example has led to the development of new market entities that act as vehicles for household savings, such as mutual funds and pension funds, as well as more leveraged entities, such as hedge funds.

The conference background paper also explains how a securities-market-based financial system works best when capital markets are liquid. In this context, liquidity refers to tradability: Markets are liquid when any individual trade is unlikely to have a major effect on the asset price because large numbers of willing traders are on the buy and sell sides of the market. Liquidity normally rests on a number of foundations; foremost are market making, trading, and arbitrage. Market makers buy and sell securities out of inventory they maintain to meet customer demand, thereby providing intertemporal liquidity to smooth out short-run imbalances in supply and demand. Traders contribute to market liquidity by trading on bets that prices will converge to long-run fundamental levels. This activity speeds the convergence of prices to fundamental levels and provides stability to the market. Systemic shocks occur when one of these foundations is compromised.

Market-oriented crises tend to begin with a large asset price decline that becomes self-sustaining. Normally, when asset prices drop sharply, investors step up to buy assets that have declined sufficiently—an action that largely prevents market stress from worsening. This type of stabilizing correction is natural for a well-functioning, efficient asset market. In systemic crises, however, investors and traders are either unable or unwilling to step in, perhaps because their losses have limited their risk-taking and market-making capacity or because a structural failure in, say, the payments or settlement system has made such a step difficult. As prices decline, more market participants either sell from a change in their risk appetite or are forced to sell by a tightening of financing constraints, and prices are pushed down. Like the self-fulfilling-prophecy aspect of the bank-run model, this sequence of events can be self-reinforcing as market participants retire to the sidelines.

Market-based systemic crises are often characterized by a coordination failure: A wide cross-section of market participants simultaneously decide to reduce risk taking and effectively refrain from financial activities, such as trading stocks, issuing debt and equity, and lending. While no one institution is necessarily insolvent or illiquid, each firm reduces its activity and risk to protect capital. In aggregate, the firms' actions combine to reduce financial market activity severely as asset prices fall, possibly harming the real economy in the process as the provision of financial services to otherwise creditworthy entities is curtailed and declines in asset prices impact firms' balance sheets. As Governor Kohn explained, the stock market crash of 1987 followed this pattern: simultaneous efforts to reduce equity market exposures were followed by a broad pullback in all risk taking.

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In a market-based systemic crisis, as in the bank-run model, the actions and beliefs of individual participants across the financial system can combine to disrupt the entire system, even though the great majority of institutions are not at risk of collapse.[5] When cast in these terms, the notion of systemic risk in the financial system bears a strong resemblance to the dynamics of many complex adaptive systems in the physical world. Many of the features of complex systems described by conference participants from the natural and mathematical sciences are clearly present in the financial system. For example, Simon Levin of Princeton University cited non-linearities, multiple stable states, hysteresis, contagion, and synchrony as features common to all complex adaptive systems. These features are evident in models of financial crises: 1) contagion is seen in the self-reinforcing character of price declines and transmission of liquidity shocks across institutions; 2) multiple stable states and hysteresis can appear in the move to an inferior but stable equilibrium; and

[4]Governor Kohn's observations, as reported in this summary, are based on his conference remarks, "The Evolving Nature of the Financial System: Financial Crises and the Role of the Central Bank."

[5]See the conference background paper described in footnote 2.

3) nonlinearities in expectations and investment decisions can lead to sharp changes in the volatility and covariation of asset prices in an apparent regime shift, as discussed by risk managers later in this introduction. This commonality between financial and other complex adaptive systems points to the broad social importance of the study of systemic events.

Systemic Risk as a Generic Problem

In the world at large, complex systems abound. Accordingly, the instability of these systems and their potential for large and potentially catastrophic regime shifts are a dominant social concern—and one of high importance to many environmental and engineering sciences. For example, atmospheric scientists examine such questions in the context of climate change, as do fishery managers concerned with the sudden collapse of certain economically important fish stocks. As the presentations by Massoud Amin of the University of Minnesota and Yacov Haimes of the University of Virginia made clear, engineers grapple with similar issues to prevent disruptions to the North American power grid and to analyze for government entities the wider economic effects of terrorist attacks.

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The ubiquity of such problems across so many fields suggests the possibility of finding common principles at work. As George Sugihara of the University of California at San Diego explained, engineers and public health professionals alike may be interested in how actions to address high-frequency but low-amplitude events, such as small floods or small outbreaks of disease, might predispose a system to low-frequency but very-high-amplitude disturbances. For instance, overuse of antibiotics to combat small-scale outbreaks of disease can lead to high-consequence outbreaks of antibiotic-resistant illnesses. Or, in an example from recent experience, the construction of levees in New Orleans to protect against intermediate-strength storm surges led to the higher consequence damage from the lower probability Hurricane Katrina.

Recent studies that have identified many common characteristics of nonlinear complex adaptive systems in the physical world may point to a tentative vocabulary of systemic risk. A key concept that can be used to describe the process of adverse systemic change in both ecology and finance is the tendency toward a rapid and large transition from one stable state to another, possibly less favorable, state—what one might call a regime shift. Levin cited this phenomenon in the eutrophication of bodies of water, in which a shock, such as excessive heat, can lead to overenrichment of the water with nutrients, resulting in excessive growth of some organisms and a depletion of oxygen that is damaging to other populations. The new state of the body of water is a new stable equilibrium. Somewhat analogously, in financial markets, an exogenous change in the economic environment can lead to new profit opportunities in certain assets that attract capital and, if investment in the assets is excessive, to an asset price bubble vulnerable to a change in investor confidence. If a shock triggers a collapse of asset prices, there is a risk of a broader contraction if the normal self-correcting features of markets fail to work. Absent those self-corrections, the flight to quality by investors seeking safe assets could become a self-sustaining transition to a state with lower levels of credit and real economic activity.

In Levin's terminology, in both situations some shock leads to coordinated behavior within the system, a process known as "synchrony"—excessive growth of nutrients in the first example and excessive investment in an asset price bubble in the second. This synchronized behavior leads to reinforcing feedbacks, causing the initial shock to spread and cause contagion. Under the combined effect of the shock and contagion, a system makes a transition, or regime shift, from a stable state to an inferior stable state while shedding energy so that it cannot readily recover its original state, a process known as "hysteresis." Levin explained that much of the research on complex systems in the natural world has focused on the properties of robustness and resilience to shocks that either can prevent regime shifts and hysteresis from taking place, or can lead to recovery if they occur.

The commonality of stability and resilience to shocks in complex systems suggests that approaches to risk management in natural and physical systems could be pertinent to financial risk management. Amin and Haimes each illustrated some of the methods for managing risk in engineering systems, such as "multi-objective trade-off analysis," in which Pareto-optimal actions are derived by considering the subjective probabilities and payoffs associated with different shocks. The methods presented bore some semblance to those used in financial risk analysis, and much of the subsequent conference discussion centered around the prospect of adapting methods from various engineering fields to financial risk management. Adaptation is clearly necessary because the range of behavior in financial markets is not mirrored in, say, the behaviors of humans operating a complex engineered system. A risk analysis of an engineered system can assume that the people involved are attempting to fulfill their roles, which are relatively defined, and share a common objective. In contrast, in the financial system traders and investors operate in a competitive environment and might change their roles and behaviors opportunistically and creatively.

Systemic Risk in the Financial System

Systemic risk in the financial system is difficult to define precisely. Although a literature on financial crises and systemic risk exists, a range of views can be found on what constitutes systemic risk.[6]

An adage among traders is that, in times of crisis, everything is correlated. Though conference participants did not share a consensus on the *definition* of systemic risk, the descriptions of systemic events by risk managers at the conference reflected this view. For example, Thomas Daula of Morgan Stanley described systemic events as regime shifts in which periods of extreme volatility combine with losses of liquidity to produce solvency risk. These crisis periods, according to Daula, "are characterized by very sharp increases in correlations and, therefore, they look and feel a lot like a regime shift—and a regime shift where you are moving from a normal regime, where there are relatively low correlations amongst financial markets, to a different regime, where you have extremely high volatility and a sharp spike in correlation."

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[6]For a central banking perspective, see Brimmer (1989); Bernanke and Gertler (1990, pp. 87-114) describe links between financial distress and the real economy. For a recent paper on systemic risk, see Chan et al. (2006).

Under such regime shifts, the normal assumptions culled from historical experience that guide day-to-day trading break down. As D. Wilson Ervin of Credit Suisse observed in regard to the Russian default and the collapse of LTCM: "The most memorable part of this episode were the questions around fundamental issues that were normally unquestioned in day-to-day activities, about the reliability of your counterparties, about how markets would work under various circumstances, about whether liquidity would be there under certain circumstances." In the presence of such uncertainty and market panic, traders can tend toward herd movement as they attempt to avoid losses—what the literature refers to as "phase locking"—and the normal mechanisms of price determination can break down. According to Robert Litzenberger of Azimuth Trust: "What happens is, in what we might refer to as crisis periods or liquidation periods . . . prices are generated internally by the market microstructure. Trades that were previously uncorrelated become correlated because they are being liquidated at the same time."

In the tentative vocabulary of systemic risk suggested above, the self-reinforcing uncertainty and market panic that can characterize a systemic episode are a clear example of contagion. The jump in correlations appearing at the onset of a systemic event can in turn be seen as an example of self-reinforcing feedback and synchrony. Furthermore, the transition from a normally functioning market to one in which prices are generated by the internal market microstructure is accompanied by widespread and simultaneous liquidations. Financing constraints and the loss of liquidity make a return to the pre-crisis state very difficult—an asymmetrical transition and example of hysteresis. Thus, the notion of systemic risk, which financial market participants are at least viscerally acquainted with, can be worked into the framework of complex systems research from other fields.

While conference participants from the financial industry agreed on the "look" and "feel" of systemic episodes, there was some diversity of opinion on the more academic question of what actually constitutes systemic risk or a systemic event. Darryll Hendricks of UBS compared systemic risk with the Loch Ness monster: People claim that it exists or must exist, but nobody can point to a definitive episode. As Hendricks noted, most definitions of systemic events involve a transmission of shocks from the financial sector to the real economy—for instance, disruptions in credit provision as well as a propagation mechanism such as self-reinforcing feedback.

Therefore, is a systemic event simply one that creates externalities? Most would probably agree that this is too low a threshold for classifying an event as systemic. Lucas put forward the idea that a proper definition of systemic risk would involve transition from a stable equilibrium to some inferior but stable equilibrium, as explained above. This idea accords well with the regime-shift characterization used by financial industry participants. However, questions remain about how to characterize these equilibria. Was an event systemic because a disturbance propagated across diverse actors through self-reinforcing feedback, or did some policy mistake form the common cause of the disturbance to all actors, such as insufficient liquidity provision during the Great Depression?

Systemic Risk and Regulation

With the range of opinions on the proper identification of systemic risk, it is natural to wonder why the definition is so important. The 1987 stock market crash and the 1998 nexus of the Russian default, the failure of LTCM, and the resulting liquidity crisis were episodes of systemic magnitude propagated and sustained by self-reinforcing mechanisms in the financial sector, and these episodes had potential consequences for the real economy. The definition is important, Daula explained, because regulation to ameliorate systemic risk constitutes a tax, and therefore a clear understanding of the risks is needed for the most protection at the lowest potential cost. Regulation is a tax in the sense that direct expenditures are required to comply with regulatory directives, and potential costs imposed in terms of efficiency losses in the allocation of capital. For an example of the latter, consider capital requirements that vary by the nature of one's business or the assets on one's balance sheet; they can create a wedge between market prices absent regulation and actual market prices. One could also wonder if a particular regulatory regime has a cost effect on the banking sector's industrial organization. For example, do certain forms of capital requirements—or, more generally, the costs of compliance with regulatory regimes—encourage consolidation?

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Given these considerations, the importance of a sound method for identifying systemic risk becomes obvious. Without it, policymakers face a strong incentive to build expansive regulatory regimes capable of influencing practices that may or may not truly reduce systemic risk, because the potentially disastrous consequences of a real systemic event would justify the costs of such regulation. As Governor Kohn stated: "The natural inclination is to take more intrusive actions that minimize the risks of immediate disruption, and this inclination is probably exacerbated by ignorance and uncertainty." He explained that too much regulation could harm efficiency or generate moral hazard as market participants begin to take regulators' corrective measures for granted and increase risk taking. For example, they may fail to engage in adequate due diligence when extending credit or fail to maintain adequate capital for the risks they undertake. Further, to borrow from a theme raised by Levin, excessive regulation could introduce rigidities that may limit the natural flexibility of markets to respond to shocks.

A detailed understanding of what constitutes systemic risk is therefore important to forming a regulatory regime that balances costs and benefits. Indeed, in all the roles policymakers fill in preventing systemic events and mitigating systemic risk, a proper analytical framework is crucial for defining the correct scope and mode of action. For central bankers in particular, a clear method for identifying systemic risk and the onset of systemic events is critical for decision making on whether and how to intervene.

The Roles of Policymakers

The Federal Reserve's role in setting monetary policy gives it the ability to mitigate the consequences of systemic events by easing access to liquidity. After the August 1998 financial market turmoil associated with the Russian loan default and the subsequent collapse of LTCM, for example, the Federal Open Market Committee lowered the target federal funds rate to soften the effects of "increasing weakness in foreign economies and of less accommodative financial conditions domestically."[7] Other policymaking roles assumed by the Federal Reserve—services provider, bank supervisor and regulator, and crisis manager—also help to position it to mitigate systemic events. As a financial services provider, the Federal Reserve, through its Fedwire system, is the backbone of the interbank payments system. The conference presentation on Fedwire, discussed in part 4 of this report, highlighted how important this role is in tempering the effects of a crisis. Referring to the hours after the attacks of September 11, 2001, the study highlighted how infrastructure disruptions and the resulting payments miscoordination threatened to seriously disrupt the payments system. In response, the Federal Reserve extended the operating

[7]Federal Open Market Committee Statement, September 29, 1998 (<http://www.federalreserve.gov/boarddocs/press/general/1998/19980929/>).

hours of Fedwire and increased liquidity provision by using the discount window and open market operations, actions that significantly reduced the impact of the disruption. This episode exemplifies the Federal Reserve's role as crisis manager.

Governor Kohn remarked that the Federal Reserve and other regulatory agencies, as banking supervisors, can do much to reduce systemic risk by maintaining a healthy banking system. Collective efforts of regulators and the private sector to enhance market discipline, improve risk management practices, and strengthen the clearing and settlement systems reduce the likelihood that a sharp change in asset prices or questions about a major market participant will lead to a systemic financial crisis. In today's market-dominated financial system, banks still have a large role to play in financing traders' securities positions and in clearing and settling trades in their brokerage activities. In their role as providers and conduits of liquidity, healthy banks can be bulwarks against the propagation of financial turmoil.[8]

As a crisis manager, the Federal Reserve can avert many problems by monitoring conditions and identifying risks as they arise. Indeed, as Governor Kohn explained, a common element in the Federal Reserve's response to both the 1987 stock market crisis and the 1998 liquidity crisis was its public acknowledgment that a crisis was under way. In announcing a crisis and articulating its response, the Federal Reserve reassured market participants that it was working to mitigate the systemic effects of the crisis; such reassurance can go a long way toward encouraging a return to risk taking. In both episodes, the Federal Reserve also used open market operations to ease reserve market conditions and the stance of monetary policy, monitored the flow of credit through the financial system, and worked with lenders to emphasize their collective interest in avoiding a credit gridlock.

The Federal Reserve's actions relied on an early determination of the potential systemic effects of the two events. Largely as a result of these actions, neither the 1987 event nor the 1998 episode led to a disruption in real economic activity.

Systemic Risk in Historical Perspective: The Events of 1998

Governor Kohn observed that the Federal Reserve has been involved in a long process of adapting its tools to the market-dominated financial system that is still emerging today. Accordingly, the 1987 stock market crash and the 1998 liquidity crisis are natural case studies to examine when defining systemic risk, as neither was triggered by the bank-run phenomenon that characterized many systemic problems in the nineteenth century.

The events of 1987 and 1998 had many common elements. First, both began with sharp movements in asset prices that were exacerbated by market conditions—portfolio insurance in 1987 and the closing out of positions in 1998. Second, market participants became highly uncertain about the dynamics of the market, the true value of assets, and the future movement of asset prices. In terms of the regime-shift scenario described earlier, events outpaced the standard risk management systems, which had been based on historical data and experience. Third, large and rapid price movements called into question the creditworthiness of counterparties, which could no longer be judged by now-obsolete financial statements. Fourth, the decline in asset prices decreased wealth and raised the cost of capital, developments that threatened to reduce both consumption and investment in the real economy.

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Although the 1987 and 1998 events shared many features, conference participants tended to focus on the more recent 1998 episode because financial institutions, instruments, and practices then were more similar to the way they are today. The potential negative effects on the real economy and the systemic character of this episode were highlighted by the withdrawal of investors from the commercial paper market.

As noted by Ervin, the events of 1998 were catalyzed by the Russian default. In 1998, Russia was in a precarious position as a fledgling democracy attempting to transition to a market-based economy. It had a high dependence on energy exports at a time when the price of oil was dropping, a massive trade deficit, an unsustainable pegged exchange rate, and a large government budget deficit. It was also financed mainly by short-term debt. Despite a large loan package in July 1998 from the International Monetary Fund, a sustained reversal in market sentiment led the Russian government to announce

[8] For analysis of banks as liquidity providers in a crisis, see Saidenberg and Strahan (1999) and Gatev, Schuermann, and Strahan (2006).

in August of that year that it would default on short-term local-currency debt. The result was disastrous: Many Russian counterparties failed, and liquidity in Russian instruments dried up.[9]

Investor losses were estimated to be on the order of $100 billion. As Ervin explained, every working assumption about the Russian market came into doubt: the rules, the participants, the prices, the functioning of markets, even the legal system. This was surely a systemic crisis for Russia. Moreover, it threatened to become a systemic crisis for the international financial system when the market turmoil affected a particular hedge fund, LTCM, and the liquidity of core markets in the financial system.

In the mid-to-late 1990s, LTCM was a very large and well-known hedge fund, both highly leveraged and highly successful. Its primary investment strategy centered on finding arbitrage opportunities or near-arbitrage opportunities in which the market seemed to be out of line with long-term economic fundamentals—a trading strategy based on the idea that certain pricing gaps will close over some (potentially long) period of time. As part of its trading strategy, Ervin explained, LTCM would tend to buy older, illiquid Treasury bonds, then short-sell current, on-the-run Treasury bonds and eke out a small yield differential between the two. The goal was to capture a small yield differential in relative asset prices, allowing LTCM to earn steady returns as relative prices converged to fair values while the fund avoided directional risk. At the time at least, this strategy was considered somewhat state-of-the-art, and many financial entities attempted to emulate it, if not to mirror LTCM's positions outright.

The primary problem with LTCM's strategy was that, as a relative-value trader, it was very exposed to liquidity shocks and correlation assumptions, even if the fundamentals underlying its positions were correct. In the days following the Russian default, there was a large flight to quality in developed markets that caused credit spreads to widen sharply. Interestingly, this trend was not limited to U.S. corporate debt; interest rate swap spreads—an indication of the credit conditions of international banks—also widened sharply. As this shock rippled through the financial system during August, it also began to affect equity markets, and the Dow dropped 357 points on August 27 and a further 512 points on August 31. Implied volatility in prices of equity options also increased substantially, more than doubling its pre-crisis levels.

These events were preceded by the decision by Salomon Brothers to close its bond arbitrage group in the spring and summer of 1998. The departure of such a large bond trader potentially left the market with less liquidity than it would have had, because of both the liquidation of Salomon's very large positions in the months prior and the absence of a large player whose trading otherwise would have contributed to market liquidity. Vincent Reinhart of the Federal Reserve's Board of Governors and Litzenberger pointed to the Salomon decision as creating the initial market stresses that escalated with the Russian default and the emergence of LTCM's financial problems.

The mechanisms that led to the subsequent fall of LTCM highlight aspects of the nonlinearities and reinforcing feedbacks cited in the conference's discussion of a securities-market-based financial system. LTCM had a strategy of targeting the volatility of the Standard and Poor's index as a type of risk control mechanism, using it as a benchmark against which to assess the value-at-risk of its own positions. VaR analysis is a widespread portfolio-management strategy that calculates the maximum potential loss over a certain time period, given a specified level of confidence. Historical volatilities are used to form a VaR estimate, Litzenberger explained. ARCH and GARCH methods (autoregressive conditional heteroskedasticity and generalized autoregressive conditional heteroskedasticity, respectively) are common tools for obtaining a volatility estimate based on historical volatility and covariance. The usual way of employing these estimation techniques at the time was to consider historical volatilities, not just volatilities during hypothetical crisis states.

The mechanisms that led to the subsequent fall of [Long-Term Capital Management] highlight aspects of the nonlinearities and reinforcing feedbacks cited in the conference's discussion of a securities-market-based financial system.

The pressure on LTCM's position caused by the liquidation of Salomon's bond arbitrage group was combined with pressure from the widening of credit spreads following the Russian default. As VaR models reflecting the spike in price volatility indicated higher risk, market participants began to liquidate their positions defensively. This reaction illustrates the concept of reinforcing feedbacks: As volatility increased, market participants reasoned that risk had also increased, so they began to liquidate those positions, a step that in turn led to further elevations in volatility and more decisions to liquidate. The process also illustrates the importance of linkages and nonlinearities in systemic events: Even though Russian instruments were a small proportion of LTCM's overall portfolio, market participants began to question their

[9]This discussion draws heavily on Ervin's conference presentation.

own rationale for holding other, non-Russian positions that LTCM also held. Thus, they began liquidating those positions in anticipation of liquidation spilling over into other markets, and in this way a seemingly small disturbance propagated quickly.

As Litzenberger explained, in the 1997 run-up to LTCM's failure, the arbitrage market was marked by high liquidity and low volatility. Under these conditions, to maintain a target risk profile (for example, VaR) when volatility was low, traders such as LTCM would leverage their positions. Recall that LTCM maintained a strategy of targeting its risk taking on the volatility of the Standard and Poor's index; the fund's response to the situation in 1997 was essentially to add leverage by returning a substantial portion of capital to its investors. This strategy was consistent with attempting to maintain profitability when trading opportunities were harder to find as trades were mean-reverting faster. According to Litzenberger, this would have been an entirely reasonable strategy if conditions in 1997 had constituted a steady state. However, the liquidation of Salomon's bond arbitrage group and the Russian default combined to disrupt this steady state and cause a considerable rise in volatility. The subsequent apparent increase in risk triggered widescale liquidations, as the assumptions underlying these positions came into serious doubt. The resulting pressure on LTCM led it to send investors a letter on September 2 asking for more capital. Just three weeks later, the firm was taken over by its creditor banks to enable orderly liquidation of the fund's positions.

Beyond the breakdown of trading models based on historical correlations, systemic events have a psychological character, as all the rules seem to collapse and participants enter into a state of high uncertainty about their counterparties.

Ervin explained that, from the viewpoint of derivatives trading desks, the events leading up to the collapse of LTCM resembled a regime shift: At times, trading in U.S. dollar interest rate swaps dried up completely; pricing for typical bonds, such as investment-grade mortgages, widened to the point that one could not get a price, or at least a real price. "During this period, people simply didn't have confidence they understood what was going on. They weren't sure they understood the new rules of the game, who would survive, and how they should play," he said.

Beyond the breakdown of trading models based on historical correlations, systemic events have a psychological character, as all the rules seem to collapse and participants enter into a state of high uncertainty about their counterparties. According to Governor Kohn, this points to a crucial role for policymakers:

> Heightened uncertainty is the key characteristic of episodes of financial instability. The central bank may not have any more information than market participants do. In economic models, based on such uncertainties, it is the central bank's willingness to act in the face of uncertainty that differentiates it from other market participants and gives it a positive role to play during financial crises.

This role must be buttressed by a clearer understanding of the fundamental dynamics underlying the securities-market-based financial system; yet many obstacles to this ideal remain, both for market participants seeking to insulate themselves from the effects of crises and especially for regulators seeking to prevent them. Among these obstacles are the difficulty in simulating financial crises, the lack of historical episodes to study, and—crucially for entities such as the Federal Reserve—hindrances to the types of data sharing among market participants and regulators that would allow central banks to act with certainty during systemic crises.

Analytical Issues

In a bank-dominated financial system, Governor Kohn observed, it is much easier to gather the information necessary to regulate effectively against the possibility of systemic disruptions. In such a context, the critical information would come from fellow bank regulators with which the Federal Reserve had been working and from banks the regulators had been examining. However, in a more market-dominated context, in which many financial institutions have a presence in many cross-border business lines, obtaining the information on counterparty exposure and risks necessary to develop cogent analyses and to inform decision making in a possible crisis requires widespread cooperation across disparate entities. Moreover, in many instances, market participants may regard this information as proprietary. Scant availability of data and inadequate data sharing present challenges for regulators and market participants alike.

Governor Kohn remarked that, as the prime source of constraint on potential crisis-causing behavior, market discipline through vigilance among private parties is always preferable to regulatory dictates. For market discipline to be effective, however, counterparties must have a clear understanding of each other's risk profile. This often requires them to share proprietary information, and confidentiality agreements between counterparties may be necessary to ensure comfort.

He acknowledged that market participants may be wary of sharing proprietary information. However, information sharing can greatly increase the probability that credit will continue to flow during systemic disruptions, resulting in a lower probability of a sustained systemic disruption, a reduced need for government intervention, and enhanced financial stability without moral hazard.

Governor Kohn added that, in a market-based system, sound risk management by *all* market participants is essential to protect against the risk of a low-probability—or "tail"—event causing a financial crisis. For example, the bringing together of practitioners in risk management policy groups can potentially lead to improved reporting of risk information to counterparties and allow best practices to be transferred across market participants with respect to valuation, exposure measurement, limit setting, and internal checks and balances. Indeed, a lesson drawn from the 1998 crisis by the President's Working Group on Financial Markets (1999) was how weakness in risk management and counterparty credit discipline enabled a firm to acquire large leveraged positions of a size that could magnify the effects of negative events.

Sound risk management practices among market participants rely heavily on sophisticated analytical methods that present challenges beyond limited data availability and information sharing.

Governor Kohn described how financial regulators, through supervision, can promote market discipline and sound risk management. The regulatory capital framework proposed in Basel II would: 1) require the largest internationally active banking organizations to enhance measurement and management of their credit and operational risks, 2) prescribe a rigorous methodology for entities to assess overall capital adequacy in relation to their risk profile, and 3) require entities to disclose publicly information about their risk profile.

Sound risk management practices among market participants rely heavily on sophisticated analytical methods that present challenges beyond limited data availability and information sharing. Discussions among economic researchers, financial market practitioners, and members of the engineering and natural sciences fields pointed to the considerable differences between the financial system and other complex systems. Among these differences is the inability to conduct or observe natural experiments on systemic crises in the financial system because crisis occurrences are too infrequent. Another difference is the role of human behavior in the financial system and the nonlinearities and anticipatory behavior it can introduce, a factor largely missing in studies of complex systems in engineering or the physical sciences. The presentations by financial market participants addressed these issues in discussions of scenario analysis.

Scenario analysis, as Daula explained, is the primary tool that market participants use to examine the risks posed by systemic events. Aside from being what it implies, scenario analysis was defined by Daula in economic terms: It starts with a particular scenario about the economy and then defines a general equilibrium, inferring the conditional expectations of all the consequences of that scenario for markets around the globe and their relative prices. He identified three ways of specifying the scenario. The first is to look at historical episodes. This approach has the advantage of being grounded in an actual event; the drawback is that changes in market structure since the chosen episode can lessen the predictive power of the analysis. A second approach is to fashion a purely hypothetical event. This has the advantage of allowing one to match the scenario to the particular market structure at the time; the obvious drawback is the difficulty knowing with certainty whether the hypothetical event is at all likely or whether the analysis performed accurately reflects how the event would actually unfold. The third approach, which addresses some of the pitfalls of the previous two, is to use a hybrid, mixing in something that may have occurred in the past in a slightly different context and analyzing how it may play out in today's context; conditional expectations for changes in market structure are adjusted along the way.

It is difficult to choose the optimal scenario to analyze. Daula suggested a method that pointed to some possible interdisciplinary linkages between this type of financial research and engineering approaches to systemic risk: Choose a set of scenarios broad enough to span collectively the types of market fluctuation likely to be encountered. If the scenarios selected are sufficiently broad, common elements may emerge. Daula emphasized, though, that this type of exercise may result in unlikely scenarios. Providing an example, he noted that one often-considered scenario is a monetary crisis in a reserve currency such as the U.S. dollar, an event that arguably has not occurred in thirty years. Incorporating extreme tail events such as these would address Litzenberger's concern that many quantitative risk management approaches rely too heavily on data from relatively benign periods and thus allow history to grant a false sense of security.

The approach of collectively analyzing a broad range of scenarios may allow for linkages with optimization methodologies from engineering fields such as operations research. Presenting one possible inroad, Haimes offered an overview of the "partitioned multi-objective risk method," in which systems are analyzed both for the low-frequency but high-cost events and for the high-frequency but low-cost events. Drawing on such mathematical work from engineering fields may also enable one to analyze how certain attempts to increase a system's resilience and robustness may actually predispose the system to low-frequency but high-damage events. Needless to say, any such analysis must be very careful in its assumptions of probability distributions.[10]

Researchers and policymakers face many challenges in arriving at a better understanding of systemic risk in our evolving securities-market-dominated financial system. Market participants and regulators face a dual problem: They must determine the factors that can trigger contagion, the prospect for sudden regime shifts, and the potential for hysteresis; they must also craft policies that strengthen resilience to the threat of systemic events in a way that neither predisposes the system to even larger disruptions nor imposes unjustifiable costs on market participants.

[10]This topic is discussed in Goldenfeld and Kadanoff (1999).

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