HANDBOOK ON SYSTEMIC RISK

The *Handbook on Systemic Risk*, written by experts in the field, provides researchers with an introduction to the multi-faceted aspects of systemic risks facing the global financial markets. The *Handbook* explores the multi-disciplinary approaches to analyzing this risk, the data requirements for further research, and the recommendations being made to avert financial crisis. The *Handbook* is designed to encourage new researchers to investigate a topic with immense societal implications as well as to provide, for those already actively involved within their own academic discipline, an introduction to the research being undertaken in other disciplines. Each chapter in the *Handbook* will provide researchers with a superior introduction to the field and with references to more advanced research articles. It is the hope of the editors that this *Handbook* will stimulate greater interdisciplinary academic research on the critically important topic of systemic risk in the global financial markets.

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CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Mexico City

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9781107023437

First published 2013

Printed and bound by Grafos SA, Arte sobre papel, Barcelona, Spain

A catalog record for this publication is available from the British Library

ISBN 978-1-107-02343-7 Hardback

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Introduction

Jean-Pierre Fouque and Joe Langsam

The intent in producing this *Handbook* is to familiarize researchers and policy makers with the many aspects of systemic risk. The *Handbook* contains some 32 chapters prepared by experts from a multitude of academic and professional backgrounds. What will become clear to the reader are both the complexity of systemic risk and the necessity for bringing together multiple academic disciplines to better understand systemic risk and for designing policies to mitigate the impact of a systemic crisis upon the global economy. Recent history has shown us not only the enormous cost of a systemic crisis but also how woefully unprepared and ill-equipped governments and private markets have been to prevent a systemic crisis or minimize its impact.

The first issue in addressing systemic risk is to define the system. Despite the large volume of recent articles on the topic of systemic risk, there has been little attention paid to what is endogenous to the system and events that are external. The financial system is a system in which humans, their emotions, politics and responses to incentives play a critical role. The topology of the system is extremely complex, dynamic, and not well studied. The system does not recognize national boundaries. Events in the US have impacted the markets across the globe. European debt crisis is impacting the Americas, Africa, and Asia. The common use of the terms "Wall Street" and "Main Street" seems to suggest that the two are separable. The contribution of the consumer to systemic risk, as evidenced by the interplay of the subprime borrowers and massive bank losses, strongly demonstrates that the "Real Economy" and the "Financial Markets" are not separable systems. Wall Street and Main Street and their international equivalents intersect numerous times. Legislation, produced to address market disruptions, in turn, changes the behavior of market participants. In a similar vein, accounting rules are proposed in response to events and, in turn, change behavior. This is a system that is continually evolving. It is a system that has proven to be robust. The ongoing crisis has painfully demonstrated that it is not so robust that one can ignore systemic risks.

What are the important components of the financial system? It is beyond the scope of this book, or of research yet undertaken, to fully answer that question. The system continues to expand in scope and new classes emerge. Ten years ago, one would have considered mortgage servicing to be an insignificant and benign component of the system. Clearly, that is not the case today. The academic community has an ever increasing important role. The theories and applications developed by academics in the fields of finance, mathematics, economics, statistics, computer science and several other disciplines have been applied, sometimes incorrectly, to create products, create trading strategies, and motivate laws and regulations. The role of technology, once considered a back office cost center activity by the banking community, has become an important profit area through the emergence of medium and high frequency trading strategies.

Research into financial markets systemic risk is still in the very early stages. There is no agreed upon definition of systemic risk. There does not exist a formal definition of a systemic crisis adequate to officially identify when a crisis began and ended. A temporary working definition for systemic risk might be:

> Systemic Risk is the risk of a disruption of the market's ability to facilitate the flows of capital that results in the reduction in the growth of the global GDP.

This definition needs refinement but captures the essential characteristics of systemic risk. Systemic risk refers to the risk that the ability of the system to function as intended is seriously degraded. It does not refer to the risk that a component or several components fail unless such failure jeopardizes the integrity of the system. Models introduced in the Mathematical Finance section of this *Handbook* demonstrate how the inter-connectedness of the system can pose the potential for a systemic crisis. Systemic risk does not refer to losses in the financial markets unless such losses impact the financial system to the extent that there is impact on economic growth. Actions that reduce the default probability of each individual systemically important institution can have the result of increasing the probability of a system wide failure.

The financial system is not deterministic. It is subjected to random shocks and evolves in response to these shocks. The financial system is exposed to many sources of risk; some are endogenous reflecting the structure of the system while others are external. External shocks include potential attacks upon the system by those opposed to a capitalist system as well as natural disasters. Market participants not only respond to regulatory policies, but also anticipate policies and regulatory actions and develop new activities in response to these anticipations.

Systemic risk research, similar to medical research, has a dual focus: preventive and curative. Policies and actions as well as data requirements required to prevent systemic crisis differ from those needed to recover from a crisis. Mitigating actions

have powerful impact upon the financial markets. Actions taken when not appropriate or that do not address current problematic factors can have strong adverse impact. A Fed easing in the midst of a crisis when credit is extremely tight and economic growth is waning has a far different impact than the same easing in periods when systemic risk attributable to excessive leverage is increasing.

This *Handbook* explores the roles of several of the important components of the financial system and explores how these areas relate to systemic risk. It is intended to be an introduction to the issues surrounding system risk. It is designed for researchers and policy makers. It is not intended to be complete, nor can it be. Much research must be undertaken before that could be done. The *Handbook* is organized into eleven Parts in the order below:

I. Data: The Prerequisite for Managing Systemic Risk
II. Statistics and Systemic Risk
III. Measuring and Regulating Systemic Risk
IV. Networks
V. Systemic Risk and Mathematical Finance
VI. Counterparty Risk and Systemic Risk
VII. Algorithmic Trading
VIII. Behavioral Finance: The Psychological Dimension Of Systemic Risk
IX. Regulation
X. Computational Issues and Requirements
XI. Accounting Issues

The reader will recognize that there is significant overlap in the topics covered in these chapters. Data issues are addressed in both the data chapter and the computational chapter. Mathematical modeling is an important feature in multiple chapters. Economics, finance, and behavioral finance are addressed in several chapters. This overlap reflects both the importance of the topics and the multiple approaches taken by different academic disciplines.

We begin the *Handbook* with a focus on data. Data is a critical component of all issues related to systemic risk. The global financial system constantly produces myriad amounts of data. This data, all too often, is inaccurate, chaotically reported, unreadable by electronic systems, and inaccessible to researchers, policy makers, investors, and regulators. Hank Paulson's book *On The Brink*, makes it clear that the critical regulators and those involved in possible bailouts had vastly insufficient information regarding the size and nature of both Lehman Brothers and AIG. The absence of accessible well-structured records of ownership and transferences of mortgages has further complicated the housing crisis.

Data released into the markets will change the behavior of the markets. Systems

will need to be developed and upgraded to report trading data using a standardized format. This will be expensive. Not every section of the market benefits from having greater transparency in the markets. New products will be engineered and trading venues may be changed to avoid reporting the data that new legislation might require. Some, data including regulatory findings regarding the credit worthiness of a bank, while not suggesting imminent credit unworthiness, could cause bank runs. The questions of what to release to the public or to researchers and when to release it are important topics for both researchers and policy makers.

H.V. Jagadish, the editor of Part I, on *Data*, states at the start of his introduction that systemic risk involves dependencies between multiple entities in the financial system. It follows that evaluation of systemic risk requires the integration of data. The first chapter, by Edward Hida II, reviews the financial information required for systemic risk modeling and the multiplicity of places (and databases) in which various components may be found. This review sets the stage for later chapters that deal with data integration, pulling together information obtained from distributed sources in support of systemic risk assessment. The second chapter, by Roger Stein, has extensive discussion of the ways in which systemic modeling objectives bear directly on the priorities and approaches for data collection or, conversely, how decisions about data strategies act to constrain the types of questions that models can answer. The Financial products Markup Language (FpML) is a language for expressing financial contracts. In the third chapter, Andrew Jacobs and Marc Gratacos present a brief overview of FpML and then describe how it could provide a basis for computer-driven analysis of conditionally dependent chains of potential events. Arnon Rosenthal and Len Seligman, in the fourth chapter, discuss the daunting task of integrating massive data and then organizing and distributing the data in functionally useful form. The authors point out the advantages of standards and the need to continue developing them while warning the reader that it is unrealistic to expect a complete set of same. Rosenthal and Seligman emphasize the need to develop data techniques, in the absence of complete standards. In the final chapter, Mike Atkin and Mike Bennett of the EDM Council describe the promise of semantic web technologies to integrate financial data for the purposes identified in preceding chapters. They also discuss the naming standards and ontologies required to get started on this semantic web based integration. The Enterprise Data Management Council is a non-profit trade association of the financial industry focused on the representation, modeling, and integration of financial data.

Data is not information. Statistics, analysis, theory, and analytics are required to extract information from data. The second Part, *Statistics and Systemic Risk*, edited by John Liechty, introduces statistical approaches to measuring systemic risk. The first of the two chapters is written by Carole Bernard, Elke Christian Brechmann and Claudia Czado. This chapter introduces the reader to several measures of trad-

ing and systemic risk. Some of these measures have been implemented with the results available on the web. Being able to measure and monitor systemic risk is critically important for macro-prudential risk management and prudent regulation. There is additional discussion about many of these measures in Part III, *Measuring and Regulating Systemic Risk*. The second chapter, written by John Liechty, introduces the reader to regime shifting models, a modeling approach that addresses the structural difference of market behavior in normal markets from those in crisis.

Part III, edited by Viral Acharya, discusses measures of systemic risk attributable to banks. The chapter by Viral Acharya, Christian Brownlees, Robert Engle, Farhang Farazmand and Matthew Richardson presents a method for using market data and regulatory stress test to compute such a measure. The chapter shows how this approach fits into the requirements of the Dodd–Frank Act to identify systemically important institutions (SIFIs). The second chapter written by Viral Acharya, Lasse Pedersen, Thomas Philippon, and Matthew Richardson proposes a method for identifying a shortfall in capital by a SIFI. The third, and final, chapter of this Part, written by Viral Acharya and Sascha Steffen, examines the international aspects of measuring systemic risk extending the analysis to Europe, Australia, and Asia. This chapter presents evidence on the consistency of performance of certain measures across these geographies.

Networks, Part IV, edited by Rama Cont, introduces network models as a methodology for understanding and modeling the relationships within the financial system. The first chapter, by Helmut Elsinger, Alfred Lehar and Martin Summer, provides a detailed study of simulation methods for insolvency contagion. The chapter by Ethan Cohen-Cole, Andrei Kirilenko and Eleonora Patacchini discusses the use of behavioral-based models in the financial markets context. They define a new measure of systemic risk and they suggest policy implications and areas for future research. The final chapter, by Rama Cont, Amal Moussa and Edson Santos, presents a quantitative methodology for analyzing the potential for contagion and systemic risk in networks of interlinked financial institutions. The authors illustrate their model with data from the Brazilian banking system. They present a strong argument that capital requirements should depend on exposures rather than balance sheet size.

Part V, *Mathematical Finance*, edited by Ronnie Sircar, provides the reader with a critically important introduction to the mathematical models of the economic and financial dynamics of the financial system. The chapters in this part provide a survey of selected mathematical models with a focus on those used in finance while also including a view of several models used in other fields. The chapter by Chris Rogers and Pawel Zaczkowski utilizes an equilibrium framework to model how the financial markets affect the real economy. Matheus Grasselli and Omneia Ismail, in their chapter, introduce agent-based models to better understand bank runs

and the motivation for the creation of interbank markets. The chapter by Josselin Garnier, George Papanicolaou, and Tzu-Wei Yang, and that by Jean-Pierre Fouque and Li-Hsien Sun present models relying on a mean-field model of diffusions to demonstrate that agent cooperation, while reducing the probabilities of default for the individual agents, can lead to increased probability of systemic failure. This approach enables one to mathematically analyze highly complex interactions and model systemic risk as large deviations from a stable state. Youngna Choi and Raphael Douady use classical perturbation theory of dynamical systems to provide a measure of instability of the global financial market. They utilize this model to investigate the effects of certain regulatory policies.

Counterparty Risk and Systemic Risk, Part VI, is edited by Kay Giesecke and investigates systemic risk issues arising from counterparty risk. The chapter by Agostino Capponi describes the mechanics of counterparty risk from both the pricing and risk management perspectives. It contains a discussion of counterparty risk problems of active research interests including the modeling of liquidity curves to capture the funding cost incurred when computing Credit Valuation Adjustment (CVA) and the systemic risk that could be attributed to CVA. Next, Jeremy Staum illustrates the importance of understanding networks. He surveys models of counterparty contagion through the payments system, through cross-holdings of debt and equity, and through derivatives exposures.

There are two chapters in Part VII, *Algorithmic Trading*, edited by Alexander Schied. The first, by Charles-Albert Lehalle investigates relationships between market design and market microstructure using examples from Europe and the USA. Key events including the May 6, 2011 "flash crash" are modeled and commented. In the second chapter, Jim Gatheral and Alexander Schied provide an overview of several order execution algorithms with extensions to incorporate dark pools. They present models that describe the empirically observed transience of price impact and optimal trading strategies associated with these models.

Part VIII, *Behavioral Finance: The Psychological Dimension of Systemic Risk*, edited by Hersh Shefrin, introduces a topic that is critically important for understanding systemic risk in the financial markets. The Part is comprised of three chapters. In the first, Andrew Lo reviews both the basic neuroscience of financial decisions and the legal and regulatory infrastructure of the financial industry in light of this research. He then discusses the implications for financial crisis, regulatory reform, and systemic risk management. The chapter by Wei Xiong reviews a set of empirical and theoretical work that provides a coherent framework of bubbles and debt crisis based on agents heterogeneous beliefs. Giovanni Barone-Adesi, Loriano Mancini, and Hersh Shefrin examine, in their chapter, crisis events between 2002 and 2009 from three interrelated perspectives: marginal expected shortfall (MES) which utilizes publically available data to construct a measure of an individual fi-

nancial firm's contribution to systemic risk; behavioral theory incorporating the concept of sentiment; and asset pricing theory.

The regulatory community is charged with supervising the financial markets. Macro prudential supervision is intended to protect the public from systemic crisis. The regulatory environment is fractured not only by geopolitical structures but also within political units. The United States has several regulatory agencies often with overlapping responsibilities. While regulators may examine almost every activity of a bank, they have limited authority to look into the activities of the shadow banking system. Regulations intended to protect the public may have unintended consequences that could increase systemic risk. "Regulatory arbitrage" is a well-established practice. It should be well recognized that market participants respond to regulatory actions that are considered to be constraints on their ability to make a profit. Understanding how the markets will evolve in response to regulatory requirements is a critically important research topic.

Part IX, *Regulation*, edited by Gary Stern, contains three chapters. The first, by Carsten Detken and Per Nymand-Andersen, presents a conceptual framework for maintaining system stability. The chapter also describes the new European supervisory architecture and compares it to the US structure. The second chapter, by Olli Castrén and Ilja Kristian Kavonius, uses Euro flow of funds data to construct a network of bilateral balance sheet exposures and then shows how local shocks can propagate through the network and result in systemic shocks. They conclude that high financial leverage and high asset volatility increase a sector's vulnerability to shocks and contagions. The third chapter, by Mikhail V. Oet, Ryan Eiben, Timothy Bianco, Dieter Gramlich, Stephen J. Ong, and Jing Wang, introduces SAFE (Systemic Assessment of the Financial Environment), an early warning system of systemic crisis developed by the Federal Reserve Bank of Cleveland. SAFE presents to institutional supervisors a toolkit of possible supervisory actions that can be used to diffuse the build-up of systemic risk in the markets.

Discussions of systemic risk often overlook the importance of technology. The financial system is heavily reliant upon computers and the internet. Computers and the systems through which the computers communicate with each other are used in every aspect of trading and risk management. The demands upon technology and the required computational power are increasing at a rapid rate. Macro-prudential regulatory supervision with potential requirements to acquire and analyze daily, if not real-time, transaction data, will require significant computational resources.

Part X, *Computational Issues and Requirements*, edited by Richard Byrne, address these problems. In the first chapter, Eric Hughes, Arnon Rosenthal, and Charles Worrell survey the computational approaches that may be needed to provide information about systemic risk and the mitigations of this risk. They also suggest future avenues of research. The chapter by Charles Worrell, Samara Guharay,

Matt McMahon, Len Seligman, and Rajani Shenoy discusses several of the many operational considerations relevant to managing a modeling environment for analyzing systemic risk. Challenges in data management, model hosting, and data security are described. Three operating models for a risk modeling forum that would assist decision makers in building consensus around data driven analysis are described. The third and final chapter written by Alan King, Donna Dillenberger, Aviv Orani, Francis Parr, and Gong Su describes a conceptual architecture for a systemic risk management system. The authors examine what this system must be able to accomplish and the resource requirements for such a system.

Part XI, *Accounting Issues*, is edited by Trevor S. Harris and covers extensive ground although it contains but one chapter. It is authored by Trevor S. Harris, Robert Herz, and Doron Nissim and explains the role, purpose and limitations of external financial reporting and suggests that there are aspects of the current accounting system that may help provide early warnings of and help mitigate potential systemic risks and others that may mask and exacerbate these risks.

The *Handbook* introduces the reader to several of the areas of interest for researchers in systemic risk. It should not be expected that for such a complex topic as systemic risk that the *Handbook* would be comprehensive. Notably absent are articles addressing politics and cyber security. The events from 2008 through 2012 illustrate how intertwined the health of the economy and financial markets are with politics. Regulators are constrained by decisions to reduce budgets or to exclude companies from specific regulatory requirements. Modeling the financial markets to better understand systemic risk must recognize that national and global political processes are parts of the system that are critical factors in times of systemic crisis. The financial system is heavily reliant upon computers and the internet. Trade data, analytics, position data, and other confidential data is passed within a firm; trading data and trade instructions are passed between firms, exchanges, clearing houses, and regulatory agencies; price information is made publically available or restricted to subscribers. Almost every aspect of daily financial activity is touched by the internet. The security of the internet and other communications systems is a source of systemic risk that has received too little attention. This is very surprising given the well-publicized damage from the massive disclosures of confidential State Department memos, given the many breaches of "secure" files by hacker groups, and given known attacks on the files of contractors to the US Defense Department. These attacks are suspected of being supported by governments anxious to gain US defense secrets. Cyber warfare poses a growing threat to the financial markets. A successful attempt to place sizable numbers of bogus trades could cause investors to lose confidence in the financial markets. A successful attempt by an unfriendly country to disrupt the internet for a significant period of time could disrupt all market activity and cause a serious systemic crisis. Greater research is

required to design better protective measures for the trading environment and for the protection of government collected position and transaction data.

The absence of an accepted definition of systemic risk was acknowledged earlier in this introduction. This is not simply an abstract academic issue. Having clear definitions is a fundamental requirement for modeling. Policy makers and regulators require coherent models of the financial markets to design policies and to anticipate the impact of actions. Effective management of systemic risk requires many of the same models required for micro-prudential regulation and for risk management of individual significantly important institutions. It also requires new classes of analytics and models to analyze networks and the evolution of the system to multiple types of shocks. These models must incorporate behavioral aspects that help explain the transition from well behaving markets to markets with increasing systemic risk and to markets in crisis. Remedial actions, whether for preventive or curative purpose, impact the financial market and have the potential for doing harm as well as good. Without a well-defined definition of systemic risk and metrics for measuring the amount and nature of the risks, it would be difficult to effectively target regulatory mitigating action without running the real risk of doing more harm than good.

This *Handbook* is designed to help educate policy makers of the importance of new research to better understand and then protect against debilitating economic crisis in the financial markets. It is designed to encourage researchers to better understand the nature of the problem. Readers of the *Handbook* should begin to understand the complexity of systemic risk. Micro-prudential regulation that addresses the stability of individual financial institutions needs to be coordinated with macro-prudential policies that address the stability of the financial system. The modern financial market with global movement of capital, complex securities and computer aided trading strategies, including high speed algorithmic trading, bears little resemblance to the financial markets for which regulations and regulatory policies were first promulgated. The models and academic theories developed for yesterday's financial markets are inadequate to address today's global markets. These need to be enhanced to capture the dynamics and evolutionary relationships among the participants in today's global financial market. Understanding the nature of systemic risk, and developing preventive and curative tools requires well-funded multi-disciplinary research. Our hope is that this *Handbook* stimulates the support and research necessary to protect the financial markets which are essential for global economic growth.