Financial Systemic Risk: a Network Science Approach

Synopsis: Bank of England Financial Stability Director Andrew Haldane's 2009 talk “Re-thinking the Financial Network" [13] was a clarion call to researchers to think of the entire financial network as a complex adaptive system, and to bring Network Science ([16]) to bear on understanding its susceptibility to global collapse.

He wrote: “Seizures in the electricity grid, degradation of ecosystems, the spread of epidemics and the disintegration of the financial system each is essentially a different branch of the same network family tree."

Inspired by this vision, and motivated by the enormous implications of the continuing problem of global financial stability, our project proposes to align Canadian academics with researchers and policy makers from the Bank of Canada and international central banks. It will connect economics-based systemic models currently being explored by central banks and reviewed in [17], with recent developments in systemic risk analysis by [6], [5] and others based on analogies with epidemics, the spread of rumours and other network phenomena. Our project will tie together concepts from network science, risk management, corporate governance and strategy, and probability theory, aiming to distinguish itself worldwide by establishing fundamental new results, while maintaining a pragmatic focus on the stability of the Canadian financial network.

The “systemic risk laboratory" we are currently developing consists of software implementations of mathematical models that view any financial network at a moment in time as banks and their balance sheets connected by interbank exposures, combined with specifications of typical bank behaviours in response to systemic stresses. The complexity of these models is scalable: as we choose, we can add more countries, and make “banks" and their behaviour more complex and diverse to include insurance companies, pension and investment funds, credit unions and corporations. We can also make links represent more complex transactions, and allow market dynamics to include realistic liquidity effects. We analyze, both by Monte Carlo simulation and by exact analysis, the “domino" or “cascade" crisis dynamics that results when different types of external stresses are applied to such a financial system. The output is a probability distribution of losses in the system, from which marginal expected shortfall (MES), systemic expected shortfall (SES), CoVaR and related systemic risk measures can be extracted. While the cascade dynamics is typically computed under the assumption that regulators do not actively control the nodes of the network during a crisis (for example by bailing them out), tools can be designed to answer questions about the effect of new regulation or about the active measures regulators may take to contain a crisis.

While our project will emphasize the behaviour of the Canadian system and target the needs of Canadian financial institutions and regulators, it will also by necessity study larger systems and their crossties. It will reach out to share best practice with regulators from other international jurisdictions and aims to push a Canadian approach to network concepts to the forefront of international research in this area of paramount strategic importance.

Research Questions: Our systemic risk laboratory is being designed to lead to powerful tools to address questions about systemic risk of both a theoretical and pragmatic nature.

1. *Phase structure of hypothetical financial systems*: The relation between basic network parameters such as connectivity, homogeneity and uncertainty, and macroscopic systemic risk measures is non-intuitive, non-linear and difficult to predict. By analogy with condensed matter physics we expect in advance that there will be phase transitions and non-monotonicity in these relations. Such emergent features will reflect profound properties of real world financial networks that can be understood by first looking at deliberately simplified network models in the style of [6, 5]. Simulation studies of complex hypothetical financial networks that map out these types of features will lead to improved understanding of the resilience of networks, and perhaps ultimately to pragmatic rules of thumb for metwork participants. This line of inquiry also links systemic network theory strongly to other areas of network science, from which we may draw additional ideas and intuition.

2. *The current network*: Even central banks and regulators have only a dim view of the interconnections between banks at a moment in time, and thus the systemic risk in the current Canadian network, and each bank's contribution to this risk, are poorly known. A natural starting point is to implement the methods of [1] in a Canadian context, basing their systemic risk measures on accessing and interpreting data on balance sheets and trading. As understanding of the most critical systemic attributes improves, this network description can be extended to wider jurisdictions and can record more detail: complex transactions such as credit risk derivatives, more complex institutional behaviour such as internal risk limit systems and responses to counterparty risk changes, and more institution types such as insurance firms, pension funds and central clearing houses.

3. *Regulatory regime change*: A new financial regulation such as Basel III's proposed limits on the liquidity coverage ratio and net stable funding ratio implies a profound change in the behaviour of the financial system. Understanding the consequences, both intended and unintended, prior to implementation is a critical question that can be addressed within our template of systemic risk. Even more important than testing a proposed change is to recognize the intuitive network rules of thumb on which a coherent regulatory regime can be based. From such an intuitive viewpoint, it is not at all clear that dramatically complexifying the rule book as proposed by Basel III will lead to the desired outcome of making financial systems more resilient.

4. *Regulatory intervention*: Effective regulatory response during a crisis requires policy makers to make rapid decisions about how and when to intervene. In the past, policymakers around the world have applied a diverse portfolio of interventions and policy changes, such as bank bailouts, opening the discount window, loosening collateral requirements or purchasing toxic assets, to react to and contain financial crises. Our network model of the banking system is planned to evolve into a testing ground for such policy responses and provide researchers and regulators with important insights on the intended and unintended consequences of any proposed intervention.

5. *Bank formation*: Addressing the question of why banks form highly interconnected networks that are prone to contagion and systemic risk is not just of theoretical interest, but also informs understanding of how effectively the financial sector performs its economic functions. Combining our balance sheet approach with network science ideas such as preferential attachment models of network creation and agent-based modelling can shed light on understanding the primary role of banks in lending to the wider economy, how banks are likely to interact, as well as the optimal design of new institutions such as central clearing houses. Understanding such issues can help in the design of regulatory paradigms that rein in systemic risk while enhancing economic development.

Personnel: Permanent Team:

- Principal Investigator: Thomas Hurd, Mathematics and Statistics, McMaster University.
- Researcher: Alfred Lehar, Haskayne School of Business, U. of Calgary.
- Researcher: James Gleeson, Mathematics, U. of Limerick.
- Researcher: Matheus Grasselli, Mathematics and Statistics, McMaster University.
- OFR Associate: Paul Glasserman, Office of Financial Research, Washington DC and Columbia Business School.

Expected Additional Personnel: McMaster U. intends to hire a leading international systemic risk researcher as an Assistant Professor in the Department of Mathematics and Statistics. In each year, we intend to have one research associate working at the postdoctoral or higher level. In addition, we intend to fund one or two PhD students at each of the three member universities.

Where We Stand Now: Members of the group have already implemented and tested a number of models of hypothetical systems that extend [6, 5], but have yet to calibrate them to real world databases. The project members' research expertise spans all major aspects of this interdisciplinary topic, including mathematical finance, network science, finance and economics, statistics, and computer science.

1. In the past five years, Hurd has made significant research contributions to portfolio credit risk and other areas of financial mathematics. Hurd and Gleeson have coauthored three papers on network approaches to systemic risk: [8], [14] and [15]. Hurd has given mini-courses on this topic at a number of Institutes, most recently at the 11th Winter School on Financial Mathematics, January 2012, Netherlands. Recently, Hurd was leader of an international problem solving workshop on Stability of Financial Networks, leading to a draft working paper entitled “Illiquidity and Insolvency: a Double Cascade Model of Financial Crises". Hurd is also writing a book “Mathematics of Systemic Risk" for the monograph series Springer Briefs on Quantitative Finance, with publication date tentatively scheduled for mid 2013.

2. Gleeson has at least nine papers in network science, of which the two most recent are [9],[3].

3. Lehar has a publication record of at least six papers focussed on systemic risk, with [4] being the most cited. His two most recent papers are [2],[7]. The last paper, coauthored with Gauthier and Souissi from the Bank of Canada, is on the topic of macroprudential capital requirements in the Canadian financial system.

4. Grasselli has re-oriented his research towards financial crisis since 2010, having taught on asset price bubbles at the Institute Henri Poincare (Paris) in 2010. He has written a paper on Minsky's Financial Instability Hypothesis [10], and a paper with an agent-based model for bank formation and interbank networks [11]. He will be a plenary speaker at the Conference “Instabilities in financial markets" to be held at the Scuola Normale Superiore di Pisa on October 18-19.

5. Glasserman is on leave from Columbia at OFR, where he is working on counterparty risk in derivatives markets, particularly credit default swaps, and the consequences for systemic risk.

Research Priorities and Timeline: Throughout the duration of the project, members will continuously monitor the rapidly developing literature coming from other systemic research groups. Where opportunities exist, for example at OFR (Office of Financial Research, Washington DC) and the ECB (European Central Bank, Frankfurt), we will work to develop partnerships, with a special aim to gain access to systemic databases. Project members will be very active in disseminating results on systemic risk. Times in brackets below denote the earliest time reportable results can be expected.

1. To refine, extend and explore our existing systemic risk laboratory based on contagion cascade models developed in [14, 15]. The principal aim is to map key features of systemic risk measures such as knife-edge properties, tipping points and non-monotonicity with respect to underlying parameters. The hope is that our findings can be summarized by intuitive rules of thumb for identifying weaknesses in networks. (6 months)

2. To develop a partnership with Bank of Canada researchers, aiming to accumulate data and analytical techniques that can be used to infer the state of the Canadian financial system, with particular attention to interbank connections and cross ties with the international banking system. (6 months)

3. To work with Bank of Canada researchers to create a realistic model of the Canadian network and then apply and test the contagion cascade framework on the resultant model. At the same time, we will work with Canadian banks to determine additional key network attributes related to the variable nature of their balance sheets and likely behavioural responses to stress. The overall aim will be to identify market stress scenarios under which the Canadian system might exhibit vulnerability. (one year)

4. To compare and where possible to align the two theoretical approaches to bank formation of [2, 11]. Thereafter, we shall address questions of optimal design of financial institutions, including the timely example of central clearing houses. (one year)

5. To create a Canadian systemic risk website. On this site, we intend to publish monthly measures of systemic risk in the Canadian network following methods outlined in [1], thereby promoting awareness and transparency on this issue. (18 months)

6. To formulate and test a variety of central bank policy alternatives, importantly those stemming from the implementation of Basel III that aim to reduce systemic risk, on refined cascade models of the Canadian financial system. (3 years)

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