Institution: King's College London

Unit of Assessment: Department of Mathematics

Title of case study: Effects of Interactions on Risk

1. Summary of the impact (indicative maximum 100 words)

Research by Reimer Kühn (RK) and collaborators has produced a framework to study and quantify the influence of interactions on risk in complex systems, including default risk in economy-wide networks of financial exposures. This work has had impact on practitioners and professional services dealing with financial risk, including research groups at central banks, who – partly in response to the recent financial crisis – have adopted such network oriented approaches to analyse and quantify systemic risk. The Financial Stability Division at the Bank of England has, for instance, developed refined versions of the network-oriented models proposed by Kühn and collaborators to specifically assess risk in the British banking system.

2. Underpinning research (indicative maximum 500 words)

From 2002 onwards, RK has been applying methods originally developed for the study of glassy systems to analyse problems of risk in networks of interacting processes or networks of mutual financial exposures. The main challenge here is to properly model the role of interactions (networks of functional dependencies) on risk for these systems, which are typically characterised by high levels of heterogeneity.

Through their ability to trigger avalanches of risk events, interactions can significantly increase the probabilities for the occurrence of systemic high-loss events in comparison to those foreseen in conventional approaches to risk. These typically take an essentially static point of view. They usually involve estimating the likelihood for the occurrence of individual risk events over a certain time horizon, as well as the distribution of losses incurred by such risk events. However losses generated by several such events are then aggregated, as if they were independent, or at best correlated. Such approaches are fundamentally incapable of describing avalanches of risk events, as would be associated with blackouts in power-grids or with significant clustering of credit-defaults as seen in the past financial crisis. This fundamental deficiency is, for instance, shared by the Basel II document which regulates the methods by which banks analyse their risks, as a consequence of which systemic risk is severely underestimated in this central regulatory document.

To overcome the deficiency, a proper dynamical approach has to be taken which allows one to describe the mechanisms by which one risk event is able to induce another via “direct contagion”, using methods which are powerful enough to capture the full heterogeneity of mutual dependencies and to allow studying the dynamics at system level.

For the important problem of *credit risk*, this was first achieved by Kühn and Neu in 2004 [1] (numbers refer to references in Sect 3) in a model which describes the stochastic dynamics of a heterogeneous network of interacting financial positions, where start-of-year wealth positions and economic impacts of defaults could be related to unconditional and conditional default probabilities of firms in the network. The results are based on earlier joint work with Neu on operational risk. A fully analytic solution of the credit risk problem, which allowed a more comprehensive overview over collective effects in contagion dynamics was obtained with Hatchett [2] in 2006. Finally, the first

ever model to include the effect of *credit default swap (CDS)* markets on contagion dynamics was proposed and solved in 2009/10 (with Heise), clearly showing the potentially destabilising nature of CDS markets at a systemic level [5]. A fully analytical solution to an *operational risk* model for networks of interacting processes [4] was obtained in 2007 (with Anand), pointing out the possibility of first order phase transitions to complete break-down in process networks, when mutual dependencies between processes are increased, e.g. in moves to increase system-efficiency.

Key Researchers

1. Dr Reimer Kühn: since 01/03 at King's College London, initially as Lecturer, 09/05 promoted to Reader, 03/11 promoted to Professor
2. Dr Peter Neu: 08/97–07/05 at Dresdner Bank Frankfurt, Director, Head of Liquidity Risk Control; 08/05–02/13 at Boston Consulting Group Frankfurt, Partner and Managing Director, Topic Leader Risk Practice Area; since 04/13 at DZ Bank Frankfurt, Division Head of Financial Controlling, Strategy and Investments
3. Dr Kartik Anand: 09/05–12/08 at King's College London, PhD student; since Nov 2012 at the Central Bank of Canada. (The risk work of Kartik Anand at KCL was supported by a Departmental DTA doctoral training grant.)
4. Dr Jonathan Hatchett: 11/04 – 03/06 at RIKEN Lab for Mathematical Neuroscience, Saitama, Japan, Post-Doc; since 08/06 at Hymans and Robertsons LLP London, Strategic Risk Consultant
5. Sebastian Heise: 09/08–07/10 at Bank of England, Economist, Financial Stability Division, and Graduate Diploma Student (PT) at King's College; since 09/10 at Yale University, New Haven, PhD Student

3. References to the research (indicative maximum of six references)

1. P. Neu and R. Kühn*, Credit Risk Enhancement in a Network of Interdependent Firms,* Physica A **342**, 639-655(2004), DOI: 10.1016/j.physa.2004.05.062

2. *J.P.L. Hatchett and R. Kühn, *Effects of Economic Interactions on Credit Risk*, J. Phys. A 39, 2231-2251 (2006), DOI: 10.1088/0305-4470/39/10/001

3. J.P.L. Hatchett and R. Kühn, Credit Contagion and Credit Risk, Quant. Fin **9, 373-382 (2009)** DOI: 10.1080/14697680802464162

4. *K. Anand and R Kühn, *Phase Transitions in Operational Risk,* Phys. Rev. E **75**, 016111 (2007), DOI: 10.1103/PhysRevE.75.016111

5. *S. Heise and R. Kühn, *Derivatives and Credit Contagion in Interconnected Networks*, Eur. Phys. J. B **85**, 115 (2012), DOI: 10.1140/epjb/e2012-20740-0

Articles marked with an asterisk best indicate the quality of the underpinning research.

4. Details of the impact (indicative maximum 750 words)

R Kühn and P Neu's cooperation on risk was triggered by questions on operational risk that arose in Neu's risk control work at Dresdner Bank, Frankfurt. It resulted in the formulation of a first interacting-processes model of operational risks inspired by statistical physics. When Neu and Kühn generalised their ideas to cover credit risk [1], this was apparently regarded as an advance by practitioners. It triggered, among other things, an invitation for RK to explain his ideas to a group of

Economists and Mathematicians of the Macro-Prudential Risks Division at the Bank of England (BoE), very soon after Neu and Kühn had posted their first results as a preprint on the Gloria Mundi web-site [A] (letters refer to sources listed in Sect 5). Since then RK has attended several further informal discussion meetings and given seminars to wider audiences at the BoE to explain progress in his credit risk modelling efforts [2,5].

As the Bank of England stepped up their efforts in network-oriented risk modelling with the onset of the financial crisis, they asked RK whether there was a suitable candidate from his group who would be able to support these efforts as an intern. This resulted in RK's PhD student Kartik Anand spending several months at the Bank, to implement and calibrate an expanded and more detailed version of the Neu-Kühn model to specifically assess risk in the British banking system. The study was to be one of the first calibrated network models developed at the BoE to highlight the propagation of economic shocks through networks of claims and obligations and to illustrate amplifying effects of asset fire sales. In its course, and with contagion through networks of financial exposures becoming to be recognized as one of the main mechanisms responsible for the unfolding of the crisis, RK was also contacted specifically to share his views and expertise on network-oriented research on risk [B]. One of the important outcomes of this line of research was to support the usefulness of its methodology for stress testing. Not in small part due to this aspect, network-oriented approaches to the analysis of systemic risk have now become firmly established as part of the research tool-kit at the Bank and other key policy institutions internationally (see Haldane, 2009; Haldane and May, 2011 [F]).

The importance of RK's recent work on the influence of CDS trading on systemic risk (with Heise) was quickly realized by practitioners, and resulted in an invitation to present these results at the 2011 Global Derivatives Trading & Risk Management Conference – the world's largest industry conference of its kind – and at the 2nd Annual Conference of the Macro-Prudential Research Network (MaRs) at the European Central Bank [D], as well as in an opportunity to present them in a seminar at the BoE in 2012. Finally, the Financial Stability Department of the Bank of Canada recently decided to use RK's CDS model, and calibrate it on real market data in one of its future policy projects aimed at creating tools to facilitate systemic stress testing of over-the-counter derivatives markets. As one of the originators of that model, RK was invited to lend his expertise to this enterprise by participating in the project.

Concerning appreciation by practitioners of RK's results and insights on collective effects in financial risks, P Neu, BCG's Head of Risk Practice Area, in a supporting letter [E] states that "*[RK's] .. results and insights have informed our discussions with regulators and our clients. Moreover, his techniques allowed us to gain a better understanding of the underlying collective effects and to create transparency and processes for mitigation measures regarding operational and credit risk management*". In 2013, Neu also spent part of his sabbatical from BCG with RK at King's College London with the specific aim of exploring one of the most important new forms of systemic financial risks and collective effects arising from a recent decision by G20 states to move substantial parts of financial derivatives trading away from over-the-counter markets and replace it by a system where such trades are conducted via central clearing houses.

Further evidence for the visibility of RK's work on risk in professional circles derives from the fact that the risk papers of RK and co-authors have between them had over 4600 downloads from the Gloria Mundi web-site [A], and that his risk modelling web page is very highly ranked in popular search engines: e.g., a Google-search for the generic search term "risk modelling" currently lists his

page second only to Wikipedia (in 2nd non-sponsored position).

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] http://gloria-mundi.com One of the main online repositories of papers consulted by practitioners, which hosts papers on various aspects of risk; includes download statistics of submitted papers. Figures given in Sect 4 concerning numbers of downloads from this site can be checked by going to the site, searching for Author "Kuhn, Reimer" and checking downloads individually for listed papers. Link to KCL-mirror of gloria-mundi search form.

[B] E-mail trail and questions document Analytical_6033092v1.pdf received from the Bank (2008); (documents available on request).

[C] http://www.bankofengland.co.uk/research/Pages/workingpapers/default.aspx Repository of working papers of the BoE dating back to 1992. A report of the study by Anand et al. was recently included in the repository as paper No 458 (document available on request). Link to KCL-mirror of BoE working paper series site.

[D] http://www.ecb.int/home/html/researcher_mars.en.html MaRs website, includes link to the 2012 conference programme (programme available on request). Link to KCL-mirror of MaRs web site and KCL-mirror of 2012 MaRs Conference Programme.

[E] Supporting letter from BCG, received and available on request.

[F] Haldane, A. 2009, *Rethinking the Financial Network*, Speech at the Financial Student Association, Amsterdam, April 2009; Haldane A. and May R. 2011, *Systemic Risk in Banking Ecosystems*, Nature 469, 351-355 (2011) (documents available on request).

1. First contact with the Bank of England initiated by the then Senior Manager of its Macro Prudential Risks Division.
2. Later meetings and consultations involved members of the Financial Stability Division at the Bank of England (testimonial about impact at BoE received and available on request).
3. The source [C] above could be consulted to verify the statement made in Sect 4 concerning the appearance of network-oriented risk research within the Bank of England.
4. Researchers at the Financial Stability Department of the Bank of Canada could confirm adoption of the Heise-Kühn CDS model for one of their projects to develop tools for systemic stress-testing of OTC derivatives markets.
5. BCG's former head of Risk Practice area, now at DZ Bank, confirmed the importance attached by his team to understanding collective effects in financial risks (see [E] above).
6. Page rank in google searches can be checked directly by performing the search indicated.