Institution: University of Essex

Unit of Assessment: 17

Title of case study: Implementing Systemic Risk Mitigation in Financial Systems: Why Interconnectedness and Complexity Matter

Period when the underpinning research was undertaken: 2000 to 2017

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Sheri Markose	Professor	1987- present

Period when the claimed impact occurred: 2013-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Essex research has changed the way in which financial risk is managed by central banks and regulators internationally. Using her network model, a systemic risk software application (App) was developed by Markose to digitally map the Indian financial system and detect financial instability for the Reserve Bank of India (RBI). This App and the Markose network model on the epidemic R number for financial contagion has been adopted by RBI and is used routinely to mitigate risk by monitoring the positions of financial institutions within the interbank market. As academic advisor to the Basel Committee for Banking Supervision (BCBS) and Financial Stability Board (FSB) for the G20 reforms for over-the-counter global derivatives markets, Markose's research was drawn upon in their Macroeconomic Impact Assessment of over-the-counter Derivatives Regulatory Reforms in 2013. Markose followed this with a 10-year 'after the financial crisis' quantitative assessment of the G20 reforms released by Banque de France at the 2017 International Monetary Fund (IMF) Spring Meeting. Markose's research continues to inform regulatory policy debate on managing systemic risk in financial systems.

2. Underpinning research [available from HEI on request]

Underpinning research started in the early 2000's when Professor Markose was Founder Director (2000-2009) of a multi-disciplinary centre (Centre for Computational Finance and Economics Agents, CCFEA) [G1]. At CCFEA Markose pioneered big data driven financial network and agent-based models, along with complexity economics marking a break with mainstream Economics and its tool sets. Markose [R1, R2] sets out the necessity for computational models and a complexity approach that mark her highly original paradigm. Markose's approach highlights the paradigm shift involved in digital systems and of system failure that occurs when uber intelligent agents interact and often at times, in response to regulation, produce novelty/surprises and radical structure changing dynamics. Markose argues that this arms-race dynamic is missing from mainstream economic models [R2]. Econometric models are of little help in surmising potential futures, and hence Markose has embarked on computational simulation models with granular data on economic agent interaction and interconnections.

[R3] sets out the first large scale agent-based computational economic model (ACE) policy related project, funded by the Foresight Office of Science and Technology that Markose undertook in 2006 when she designed a smart market for congestion. This experience of designing smart markets for negative externalities based on 'polluter pays principle' to avoid unsustainable outcomes, has been incorporated in her systemic risk models to design a Pigou tax on those financial institutions that undertook excessive risk taking that can jeopardize entire economies.

Markose's CCFEA research on network analyses to track financial and economic contagion, led to Markose's appointment as consultant to the International Monetary Fund (IMF) in 2012. Her holistic model of the interconnectedness of the global derivatives markets was the first of its kind. The IMF Working Paper [R4] on systemic risk from global derivatives, demonstrated using what has become an iconic network graph based on large scale data, the fallacy of composition inherent to models of modern risk management. What is individually optimal may be destabilizing for the system as a whole when risk is removed from individual balance sheets of banks, but concentrated at the system level with 16 broker dealer global banks in the derivatives market. The USD700trillion derivatives markets were implicated in the 2007 financial crisis and Markose became influential in the G20 reform of the over the counter (OTC) derivatives.

The papers [R4-R8] set out and refine further this network framework for financial contagion that underpins the RBI financial network App [R9] based on the 'eigen-pair' method which simultaneously gives a metric, analogous to the epidemic R number, for the tipping points for the instability of the system, along with a Google page rank-like metric for intermediaries who are systemically important, and those that are systemically vulnerable. This work challenges the mainstream measures of risk. Markose [R5] has emphasized the paradox of volatility in market price based systemic risk indices which underestimates risk during asset booms and will spike only contemporaneously with the crisis, giving no early warning. In order to avoid model risk in the estimation of financial networks, Markose has underscored the necessity to mandate who-to-whom financial bilateral data [R9]. The Markose-Giansante [R6, R9] systemic risk analytics yields an analogue of the epidemic R number for the financial system and also signals which institutions are potential super-spreaders or are likely to fail. This along with a quantification of the losses based on real (rather than proxied) financial exposures, makes the App a powerful tool. All of this underpins the RBI systemic risk App, which has also allowed her to repurpose the software to give an assessment of the efficacy of the G20 reforms for over-the-counter derivatives in terms of the Central Clearing Platforms (CCPs). Markose, with her group [R8], designed skin-in-the game capital requirements for CCPs to mitigate their potential to become super systemic and require tax-payer bailout. Markose credits her complexity perspective to her commitment to using software based holistic network methods to model the financial system and to simulate the impact of policy.

3. References to the research [available from HEI on request]

[R1] Markose, S. M. (2005), "Computability and Evolutionary Complexity: Markets as Complex Adaptive Systems (CAS)", Economic Journal, 115 (504), F159-F192. https://doi.org/10.1111/j.1468-0297.2005.01000.x

[R2] Markose, S.M. (2017) "Complex Type 4 Structure Changing Dynamics of Digital Agents: Nash Equilibria of a Game with Arms Race in Innovations", Journal of Dynamics and Games, 4 (3). 255 - 284 http://doi.org/10.3934/jdg.2017015

[R3] Markose S., Alentorn A., Koesrindartoto D., Allen P., Blythe P. and Grosso S., (2007), "A smart market for passenger road transport (SMPRT) congestion: An application of computational mechanism design", Journal of Economic Dynamics and Control, 31 (6) 2001-2032, http://doi.org/10.1016/j.jedc.2007.01.005

[R4] Markose, S. (2012) Systemic Risk from Global Financial Derivatives: A Network Analysis of Contagion and its Mitigation with Super-Spreader Tax. International Monetary Fund Working Paper. November; 12/282 ISBN 9781475577501

[R5] Markose, S.M. (2013) Systemic Risk Analytics: A Data Driven Multi-Agent Financial Network (MAFN) Approach, August 2013, Journal of Banking Regulation, 14,285-305 http://doi.org/10.1057/jbr.2013.10

[R6] Markose, S., S. Giansante, and A. Shaghaghi, (2012), "Too Interconnected To Fail Financial Network of U.S. CDS Market: Topological Fragility and Systemic Risk", Journal of Economic Behaviour & Organization, 83 (3) 627–646. http://dx.doi.org/10.1016/j.jebo.2012.05.016

[R7] Heath, A., Kelly, G., Manning, M., Markose, S., & Shaghaghi, A. R. (2016). "CCPs and Network Stability in OTC Derivatives Markets". Journal of Financial Stability, 27, 217-233

https://doi.org/10.1016/j.jfs.2015.12.004

[R8] Markose, S., Giansante, S., & Rais Shaghaghi, A. (2017). "A Systemic Risk Assessment of OTC Derivatives Reforms and Skin-in-the-game for CCPs", Banque de France Financial Stability Review, 21, 111-126. https://publications.banque-france.fr/en/april-2017

[R9] Markose,S and Giansante, S. (2014) Reserve Bank of India (RBI) Systemic Risk Analytics App User Guide. Holistic Visualization and Stress Test App for the Financial System (Available on request)

Grants

[G1] Markose, S. Marie Curie Research Training Network (RTN) on Computational Optimization Methods in Statistics, Econometrics and Finance (COMISEF) funded by the European Union. 2007-2013 €2.6million (£250,605 to Essex).

[G2] Markose, S. Diversity in Macroeconomics New Perspectives from Agent-based Computational, Complexity and Behavioural Economics. ESRC Conference Grant, 2014, £30,000

4. Details of the impact

Modelling and reducing systemic risk (the Reserve Bank of India)

Based on her research [R4,R5], Markose developed one of the earliest and most comprehensive implementations of a large scale data driven financial network software application (App) undertaken for financial systemic risk management in a large economy [S1].The outputs from the network model and App enabled the Reserve Bank of India (RBI) to manage systemic risk in a timely basis [S1]. Since 2013, RBI has added the Markose systemic risk network App to their toolbox for monitoring and controlling risk in their financial system. Analysis using the App appears annually in the RBI Financial Stability Reports [S2].

In the aftermath of the Great Financial Crisis when it was recognized that mainstream financial risk management and macro-economic models failed, central banks were setting up Financial Stability Units the world over to develop more system-wide network-based models for tracking financial contagion. Based on her research [R4, R5, R6], Markose was appointed Senior Consultant (between 2011 and 2015) for the digital mapping of the Indian Financial System at the newly formed Financial Stability Unit of the Reserve Bank of India [S3]. The JAVA software of a multilayer network that covers 1,500 Indian financial institutions, including banks and non-banks such as insurance companies and mutual funds, was developed by Markose in collaboration with Dr Simone Giansante [R9]. Through this project the RBI became one of the first central banks to mandate bilateral who-to-whom granular balance sheet data from their financial institutions to set up the digital map of financial flows. As the IMF note this was yet to become the standard in many countries where typically, central banks and mainstream macro-economic models use highly aggregated data which ignore the actual interbank credit flows and also institutional details that are causal in the ensuing crisis [S1].

The outputs from the granular network model allowed RBI to mitigate the systemic risk which identified that an Indian bank was borrowing aggressively in the interbank market and becoming a threat to the system. A network metric developed by Markose-Giansante showed that this bank, not one of the usual suspects, suddenly moved from rank number five to first rank in terms of network centrality metric over a period of 18 months, signalling its growing threat to the system. Indian regulators benefitted from the early warning capabilities that this network modelling of interconnected balance sheets of financial institutions provides [S1]. Markose produced a detailed handbook [R9] for the systemic risk App for the RBI Financial Stability Unit staff as well as training them in the theory behind the financial network methods [S4].

The IMF Deputy Director Asia Pacific, who conducted the Financial Stability Assessment Program (FSAP) for the Reserve Bank of India stated [S1]:

> *"The Indian regulators have benefitted from the early warning capabilities that this network modelling of interconnected balance sheet of financial institutions provides... [and] has greatly enhanced the ability of the India regulators to manage systemic risk in a timely basis. It must be noted that Professor Markose first developed some of the methods*

behind this RBI software for an IMF project on the systemic risk for global derivatives, and this is an area she continues to have considerable impact…it is a remarkable achievement for the project that Markose and Giansante pull off this software implementation..."

G20 Reforms of Over-the-Counter Derivatives market

A collaborative IMF research project led by Markose on the Systemic Risk from Global Financial Derivatives Markets using network analysis in 2012 led to her appointment as an academic advisor for the implementation of the G20 reforms of the global derivatives markets.

As one of only four Academic Advisors to the G20 Over-the-Counter Derivatives Coordination Group (ODCG) of the Basel Committee on Banking Supervision and Financial Stability Board, Markose research [R4, R5] was drawn upon in the 2013 Macroeconomic Impact Assessment of OTC Derivatives Regulatory Reforms Report published by the Bank for International Settlements (BIS) [S5]. BIS chaired the ODCG which evaluated the combined effects of the regulatory reforms that were being implemented following the financial crisis of 2007-2008. The BIS study, completed under the aegis of Mark Carney as head of the FSB confirmed the primary result that the net benefit of these reforms was roughly 0.12% of global GDP per year justifying the cost to the banks of the proposed reform changes, which have in turn led to a reduction in the counter party risk in Over-the-Counter derivative markets [S5].

In the 10-year retrospective of the Great Financial Crisis, Markose was invited to analyse the impact of the G20 financial reforms of global derivatives markets [S6] for the Banque de France Financial Stability Review 2017 [R8]. Markose's research and model gave a data driven depiction of the stability or lack of it, for the extant 2017 market infrastructure involving Central Clearing Platforms (CCP) for derivatives clearing and gives proof of concept for the design of skin-in-game capital requirements for CCPs so that they do not need to be bailed out by tax payers [R8].

In 2017 the Governor of the Banque de France, championed Markose research and further stated [S7]:

"This 21st edition of the Stability Review [R8] shows that the banking and financial regulations adopted since the crisis constitute a major acquis to be preserved because they have made the global financial system more robust. It also stresses the importance of a regular assessment of their impacts in order to consolidate this acquis. Our common challenge now is to preserve and enhance it".

Informing regulatory policy debate on systemic risk in banking systems

Markose's research continues to be drawn upon in regulatory policy debate for example: On 4 July 2018, Markose gave an assessment of systemic risk from Brexit [S8] at the Westminster Business Forum: Building a resilient UK financial sector - next steps for prudential regulation, structural reform and mitigating risks alongside the Deputy Governor and Executive Director of the Bank of England. Attendees included members of Treasury Select Committees. Markose warned about a potential misfiring of repo markets due to the conditions highlighted in her 2017 Banque de France Review [R8] and paper [R7] co-authored with Bank of England and Reserve Bank of Australia staff on the large demand for high quality liquid assets needed for CCP clearing and settlement. As monetary and financial systems become increasingly digital, Markose's expertise led to an invitation as a panellist on systemic risk from cyber-attacks at the March 2020 Bank of England Conference on the Impact of Artificial Intelligence (AI) and Machine learning on the UK Economy [S9].

5. Sources to corroborate the impact

[S1] Testimonial from IMF Deputy Director Asia Pacific.

[S2] PDF Compilation of Financial Stability Reports (FSR) of the Reserve Bank of India show that the Markose-Giansante systemic risk App has been routinely used since 2013:

[S2a] Annual RBI FSR December 2013 page 23

[S2b] Annual RBI FSR 2014 page 34

[S2c] Annual RBI FSR 2015 page 35

[S2d] Annual RBI FSR 2016 page 34

[S2e] Annual RBI FSR 2017 page 34

[S2f] Annual RBI FSR 2018 page 41

[S2g] Annual RBI FSR 2019 page 47.

[S3] The Global Treasurer 2011 RBI Appoints Professor Sheri Markose for Financial Stability Advice

[S4] Testimonial from Reserve Bank of India on the Systemic Risk Financial Network Software project lead by Markose from 2011-2015.

[S5] Macroeconomic impact assessment of OTC derivatives regulatory reforms (August 2013). p.22, p62 Annex 5 page 75 lists Markose as an Academic Advisor.

[S6] 2017 Banque de France (BDF): Press Release on *Financial Stability Report.*

[S7] Testimonial from Banque de France, Governor on 10-year post Great Financial Crisis assessment of G20 Financial Reforms.

[S8] Westminster Business Forum. Building a resilient UK financial sector - next steps for prudential regulation, structural reform and mitigating risks. 4 July 2018. Transcript p. 33 onwards.

[S9] Markose was Panellist on Systemic Risk at March 2020 Bank of England Conference on AI and Machine Learning (programme and screenshot of event details).