Institution: London School of Economics and Political Science		
Unit of Assessment: 10 - Mathematical Sciences		
Title of case study: Improving financial stress testing at the Bank of England		
Period when the underpinning research was undertaken: 2010-2020		
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:**
Luitgard A. M. Veraart	Associate Professor of Mathematics	2010 to present
Period when the claimed impact occurred: 2016-2020		
Is this case study continued from a case study submitted in 2014? No		

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

LSE research on systemic risk and financial contagion in financial markets has informed the work of policymakers at the Bank of England (BoE), helping to protect and enhance financial stability in the UK and beyond. It has particularly informed the inclusion by the BoE of a model for financial contagion in its annual concurrent stress test in 2016 and 2017; that model builds on a framework developed by the LSE. In both these years the BoE stress test covered seven major UK banks and building societies: Barclays, HSBC, Lloyds Banking Group, Nationwide, The Royal Bank of Scotland Group, Santander UK, and Standard Chartered. These banks and building societies (hereafter referred to collectively as "banks") account for around 80% of banks' lending to the UK real economy regulated by the Prudential Regulation Authority. Ensuring that they are able to withstand a potential financial shock is therefore important to maintaining the wider financial stability of the country.

2. Underpinning research (indicative maximum 500 words)

The research underpinning impacts described here was carried out within a wider body of work conducted by Dr Luitgard Veraart on the use of network models to assess systemic risk and financial stability. In a 2013 paper **[1]**, Veraart and her co-author Professor L. C. G. Rogers (University of Cambridge) modelled the interbank market as a directed graph of interbank obligations. If one or more banks default on their payment obligations, losses spread throughout the network and can cause other banks in the system to default. The model described in **[1]** allows users to compute how much each of these banks is able to pay at the end of the default cascade. These payments are referred to as clearing payments.

The model set out in **[1]** builds on the modelling paradigm of Eisenberg and Noe (2001) but includes the important additional feature of allowing for default costs. This immediately introduces novel and realistic effects, since the presence of default costs significantly changes the default cascade. Without default costs, the network spreads losses, but cannot amplify them. In the presence of default costs, however, the initial losses causing an institution to default can be substantially amplified while the default cascade runs its course.

Because these amplification effects are a key concern for policymakers, it is important to ensure that they are captured in the models used in today's stress tests. In a paper on default contagion in financial networks **[2]**, Veraart generalised the framework outlined in **[1]** to allow for financial contagion to be triggered, not necessarily by the default of an institution alone, but also by mark-to-market effects. These effects were a vital driver of losses in the 2007-2009 Global Financial Crisis. The paper **[2]** further illustrated the ways in which the framework described in **[1]** and generalised in **[2]** could, in principle, also be applied even if only partial information is available about the underlying network of exposures. This can be achieved

using a Bayesian approach to systemic risk assessment, which Veraart had previously developed in **[3]** and **[4]**.

More recently, Veraart has undertaken a new programme of collaborative research with the Bank of England on developing models for and analysis of system-wide stress. This research has analysed liquidity stress in the repurchase agreement (repo) market, looking at the wider financial system beyond the banking sector. A particular focus of the analysis was on liquidity stress during the early phase of the Covid-19 pandemic.

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

[1] Rogers, L. C. G. and Veraart, L. A. M. (2013). Failure and rescue in an interbank network. *Management Science*, 59(4), pp. 882-898. DOI: 10.1287/mnsc.1120.1569. Work on this output began in 2007, but the paper was very significantly refined and extended between Veraart joining LSE in September 2010 and its acceptance for publication in February 2012.

[2] Veraart, L. A. M. (2020). Distress and default contagion in financial networks. *Mathematical Finance*, 30(3), pp. 705-737. DOI: 10.1111/mafi.12247.

[3] Gandy, A. and Veraart, L. A. M. (2017). A Bayesian methodology for systemic risk assessment in financial networks. *Management Science*, 63(12), pp. 4428-4446. DOI: 10.1287/mnsc.2016.2546.

[4] Gandy, A. and Veraart, L. A. M. (2019). Adjustable network reconstruction with applications to CDS exposures. *Journal of Multivariate Analysis*, 172, pp. 193-209. DOI: 10.1016/j.jmva.2018.08.011.

Based partly on the research described above, Veraart was the co-winner of the University of Cambridge Adams Prize 2019, awarded each year by the Faculty of Mathematics and St John's College to UK-based researchers under the age of 40 conducting first-class international research in the mathematical sciences. The Adams Prize is one of the oldest and most prestigious prizes awarded by the University of Cambridge.

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

Veraart has worked regularly with the Bank of England (BoE) since 2015. From October to December 2016, she served as a BoE George Fellow, in which capacity she was based full-time in the Stress Testing Strategy Division of the Financial Stability Strategy and Risk directorate **[A]**. The primary impact of the research outlined above is its use by the BoE to conduct stress testing in 2016 and 2017. Its use in this context means that the research has contributed to the fulfilment of one of the BoE's key objectives: to protect and enhance the stability of the UK financial system.

Helping meet statutory objectives

The main aim of the BoE's stress testing framework is to help the Financial Policy Committee (FPC) and the Prudential Regulation Authority (PRA) to meet their statutory objectives. The FPC's primary objective is to contribute to the BoE's financial stability objective to protect and enhance the stability of the UK financial system. It is also a general objective of the PRA to promote the safety and soundness of the banks it regulates. Stress testing, which is used to analyse the resilience of an object or system under extreme (adverse) conditions, supports both of these objectives. Stress tests are used both to measure risks and to manage risk by setting prudential policy. Their use in finance has significantly increased since the 2007-2009 Global Financial Crisis, which showed the fault lines of existing risk management practice. Following recommendations made by the Basel Committee on Banking Supervision (the primary global standard-setter for the prudential regulation of banks), regulators around the

world have developed and implemented new stress testing frameworks to both measure and manage risk in financial markets. The Basel Committee notes that: "Stress testing is now a critical element of risk management for banks and a core tool for banking supervisors and macroprudential authorities" **[B]**.

New tools for UK stress testing

In the United Kingdom, the BoE has conducted an annual stress test since 2014. The main purpose of this is to "provide a quantitative, forward-looking assessment of the capital adequacy of the UK banking system and individual institutions within it" **[C**, p. 7**]**. The first part of a stress test is to design a stress scenario. Each year since 2016, the BoE has considered a scenario whose severity reflects policymakers' assessment of the current risk environment. This so-called "annual cyclical scenario" (ACS) is used to test the resilience of the UK banking system to factors such as deep simultaneous recessions in the UK and global economies and financial market stresses. The ACS is counter-cyclical, meaning it will be more severe during market conditions in which a large amount of risk has built up and less severe when these risks have realised or decreased. Additional scenarios are considered biannually.

The second part of the stress testing exercise is concerned with evaluating the impact of the stress scenario on banks' balance sheets and, in particular, their capital positions. It is important that suitable models and methods are used to conduct this analysis, because the results of the stress testing exercise are used to set regulatory capital buffers and to determine whether banks need to improve their capital positions **[D]**. The LSE research described here has had impacts on this aspect of the BoE stress test.

In 2015, the BoE identified the modelling of system-wide dynamics and feedback mechanisms as a key priority for its stress testing framework. As a result, it particularly sought to develop tools facilitating the exploration of system-wide dynamics. The 2007-2009 crisis had demonstrated the vital importance of spillovers and feedback channels - both between financial institutions and between the financial sector and the real economy - to quantifying the likely impacts of financial stresses. The need to understand these channels made analysis of them, such as that of the interbank lending channel analysed in **[1]**, an important element of stress tests.

Testing solvency contagion via interbank lending

In 2016, the BoE stress test included, for the first time, testing of solvency contagion via interbank lending **[E**, p.34**]**. The BoE's solvency contagion model examines how deteriorating capital positions lead to revaluation of interbank debt claims, which can in turn further affect banks' capital positions. The model used to conduct the solvency contagion test introduced in 2016 builds on the modelling framework set out in **[1]**. This is particularly apparent in its newly explicit inclusion of exogenous bankruptcy costs within the modelling framework. A subsequent BoE Staff Working Paper describing the development of the new solvency contagion model cites both **[1]** and **[3]** and acknowledges Veraart's input **[F]**. The Executive Director of Financial Stability Strategy and Risk has subsequently further confirmed the importance of the underpinning research to the development of the BoE's stress testing:

> "*[Veraart's] research has informed the Bank's modelling and analysis, in particular on incorporating feedback and amplification mechanisms in the Bank of England annual cyclical scenario (ACS) stress test. Solvency contagion was the first amplification mechanism included in the Bank of England's stress test in 2016. The methodology […] builds on research by Dr Veraart, in particular her work on financial networks (Rogers and Veraart (2013)* **[1]**)." **[A]**

Understanding and incorporating feedback loops and amplification effects is paramount. In a 2017 speech, the BoE Executive Director for Financial Stability Strategy and Risk stated that it was these feedback loops that "helped to turn around USD300 billion of subprime mortgage-related losses into well over" USD2.5 trillion of potential write-downs in the global banking sector within one year **[G**, p.6**]**.

The new model, which was also used as part of the 2017 stress test **[H]**, helped to address two of the BoE's key priorities: "*developing a genuinely macroprudential approach to identifying risks in the banking sector; and enhancing the Bank's modelling capabilities as part of the concurrent stress tests of the banking system*" **[E]**.

Supporting stability during the Covid-19 pandemic

Veraart's work on financial stability has continued to deliver further benefits for the BoE beyond these direct impacts on the 2016 and 2017 stress tests. In 2020, for example, she worked with economists at the BoE to explore liquidity stress in the repo market, looking at the wider financial system beyond the banking sector. As the BoE Executive Director of Financial Stability Strategy and Risk explains, this more recent work "*has informed policymakers in the context of analysing the stress in financial markets observed during the Covid-19 pandemic*" **[A]**. Veraart's contribution to the BoE's work on financial stability is further realised through her membership of the Academic Advisory Group to the One Bank Research Steering Committee, which oversees the direction of the BoE's research.

Adams Prize

The development of new tools supporting financial stability was recognised in the aforementioned award to Veraart of the 2019 University of Cambridge Adams Prize. Professor Mihalis Dafermos, Chair of the Adams Prize Adjudicators, noted that:

> "*Dr Veraart has developed new tools and concepts relevant for the representation and analysis of financial stability and systemic risk in banking networks. Her work has had considerable visibility and impact, both within academia and outside*" **[I]**.

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

[A] Supporting statement from Executive Director, Financial Stability Strategy and Risk, Bank of England (and also a member of the Financial Policy Committee), 18 December 2020.

[B] Basel Committee on Banking Supervision (October 2018), "Stress testing principles". This replaces Basel Committee on Banking Supervision (May 2009), "Principles for sound stress testing practices and supervision".

[C] Bank of England (October 2013), "A framework for stress testing the UK banking system". Discussion paper.

[D] Bank of England (October 2015), "The Bank of England's approach to stress testing the UK banking system".

[E] Bank of England (November 2016), "Stress testing the UK banking system: 2016 results". See, especially, p. 34, Box 3, which refers to the model described in **[F]**.

[F] Bardoscia, M, Barucca, P., Brinley Codd, A., and Hill, J. (2017), "The decline of solvency contagion risk", Bank of England Staff Working Paper No. 662. See pp. 3, 6, and 9 for reference to **[1]** and p. 4 for reference to **[3]**. Veraart's input is also referenced in the Acknowledgments (p. 17). The source code used to run the simulations, referenced at p. 18 (available at https://github.com/marcobardoscia/Neva) includes a file ibeval.py which

contains a function rogers_veraart (definition starts on line 353). This implements in Python the model proposed in **[1]**.

[G] "How to: MACROPRU. 5 principles for macroprudential policy", speech given by Executive Director for Financial Stability Strategy and Risk, Bank of England, at the London School of Economics Financial Regulation Seminar, 13 February 2017.

[H] Bank of England (November 2017), "Stress testing the UK banking system: 2017 results". For use of the solvency contagion model beyond 2016, see p. 40.

[I] "Adams Prize winners 2018-19 announced", St John's College, University of Cambridge, 5 March 2019.