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A framework for modelling system-wide stress dynamics

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Second Conference on Network Models and Stress Testing for Financial Stability, Mexico City, 26-27 September 2017

Disclaimer: The views here are the views of the authors and do not necessarily reflect the views of the Bank of England.

Lessons from the financial crisis

- **‘Local’ shocks amplify and propagate through a variety of mechanisms, across multiple sectors**
  1. Interaction between contagion channels matters
  2. Interaction between sectors matters
  3. Interaction between constraints matters
- Systemic risk can only be understood by considering the whole: Joint ≠ Sum of Parts (Brazier 2017)
- Core goal of a system-wide stress test: capture systemic risk
  - To fulfil goal: must capture 1)-3)

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Main message

We propose a **framework** for system-wide stress simulations, and we produce a **stylised example** that illustrates how this framework captures multiple channels of contagion across sectors.

We initialise a **multi-layered network** and **simulate its evolution**.

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Outline

- Research context
- A general **framework**
- A **stylised model**
- Illustrative results
- Next steps and key questions

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Models of contagion in the financial system

- Initially lot of focus on *individual* contagion mechanisms in the banking sector…
  - Solvency contagion (Eisenberg and Noe (2001), Bardoscia (2015))
  - Liquidity contagion (Allen and Gale (2000))
  - Price-mediated contagion (Greenwood (2015), Cont and Schaanning (2014))
  - Funding/solvency interactions (Anand (2015), Bank of England (2012))
- Now more modelling of **multiple, interacting contagion channels**
  - Montagna (2014) , Caccioli et al (2014), Poledna et al. (2015), ECB (2016)

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Models of contagion in the financial system

- Banks and non-banks equally sized
  - Report of Financial Structures (ECB 2015), Mapping the UK Banking System (Burrows et al. 2015)
- Banks and Non-Bank Nexus
  - Pozsar and Singh (2011)
- Growing literature on the role of **non-banks, and interaction of sectors**
  - Brunnermeier and Pedersen (2009)
  - Lengwiler and Maringer (2011)
  - Baranova et al (2017)
  - Bookstaber (2014)

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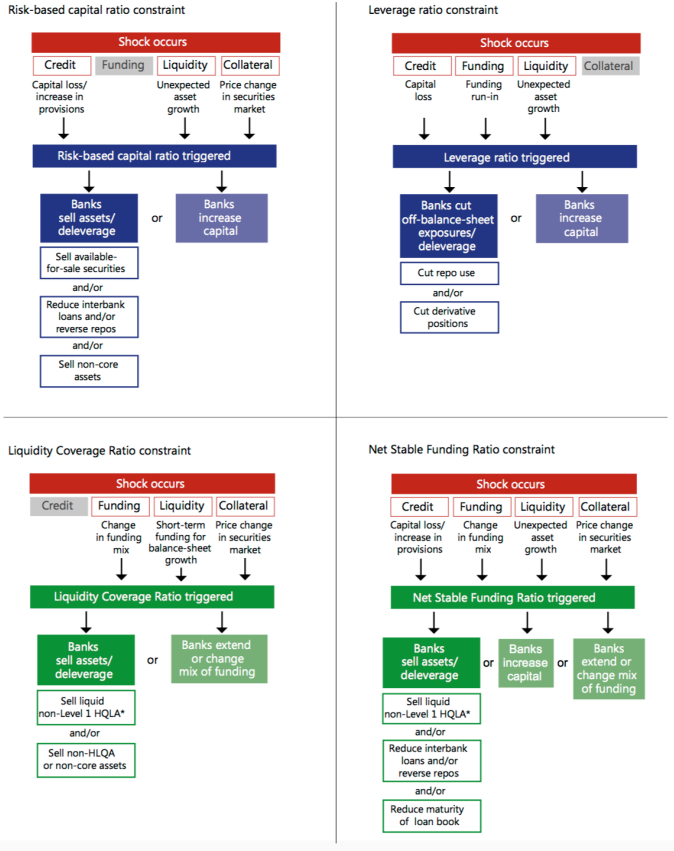
The frontiers of research/modelling

- Initial efforts focused on considering the effect of single constraints in driving contagion
  - E.g. leverage constraint to drive firesale dynamics (Greenwood 2015), zero equity constraint to drive post-default contagion (Caccioli 2014)
  - Behaviour not known. Constraints drive behaviour
- More and more the role of **multiple (interacting) constraints** is considered in driving contagion
  - IMF (2017), *BIS (2015),* Cecchetti and Kashyap (forthcoming)
  - Gives insight into direction and and type of contagion



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The frontiers of research/modelling

- What is missing?
  - **COHERENT** way to be able to **jointly** model multiple: (1) interacting sectors; (2) contagion channels; (3) constraints.
    - **Joint ≠ Sum of Parts** (Brazier 2017)
    - Need to **know joint** to **capture systemic risk**
  - **Purpose of system-wide stress testing** is to assess system-wide financial stability, identify sources of systemic risk, and evaluate policies to mitigate systemic risk.
    - So need to consider **joint**
    - But, must be able to consider the parts in isolation too! Need **framework that can implement models** that are **comprehensive or simple**, so as to make it suitable to answer the research or policy question posed.

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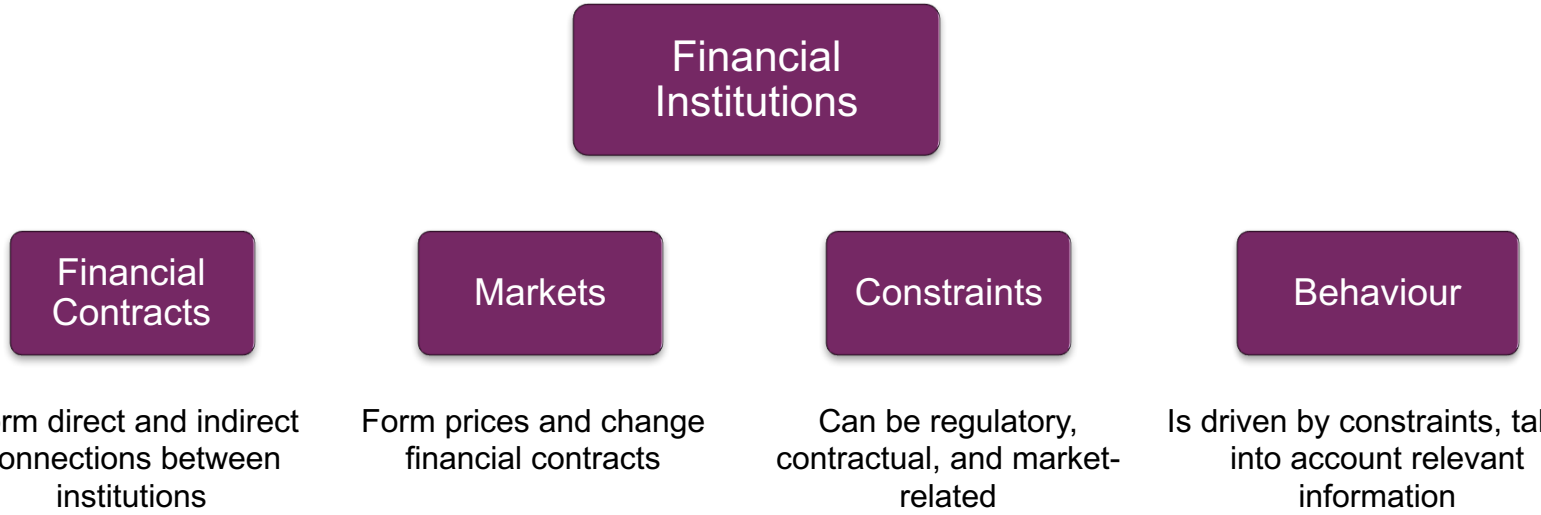
Building blocks for system-wide stress testing



Building blocks for system-wide stress testing

1. Specify initial balance sheets at time zero

Financial Institutions

Financial Contracts

Markets

Constraints

Behaviour

=> We obtain a (bi-partite) multiplex network

Nodes: institutions

Edges: direct connections AND indirect connections

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Building blocks for system-wide stress testing

1. Specify initial balance sheets at time zero

Financial Institutions

2. Specify markets, constraints and behaviour

Financial Contracts | **Markets** | **Constraints** | **Behaviour**

=> We obtain a (bi-partite) multiplex network

Nodes: institutions

Edges: direct connections AND indirect connections

⇒ We can simulate the evolution of the network

Obtain sensitivity analysis

Perform policy experiments

Switch components on/off

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Economic Simulation Library (ESL)

- **Modular**: switch components on/off and host various models
- **Flexible**: can accommodate a variety of options for each component
- **Transparent**: prints detailed log and intermediate outputs

- Economic Simulation Library (ESL): https://economicsl.github.io
- Developed at the Institute of New Economic Thinking (INET) in Oxford under supervision of J. Doyne Farmer

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Implementing a Model Using the Framework

I. Implementing Building Blocks
II. Multi-Layered Bi-Partite Network
   - Initialisation
   - Evolution
III. Generating Outputs

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I . Building Blocks to Implement

Financial Institutions

Financial Contracts	Markets	Constraints	Behaviour
Form direct and indirect connections between institutions	Form prices and change financial contracts	Can be regulatory, contractual, and market-related	Is driven by constraints, takes into account relevant information

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1. Financial Institutions

- Financial institution can be represented by a balance sheet;
  - A balance sheet must be seen as **collection of financial contracts**; this collection is institution-specific
- Types financial institutions considered in current stylised model:
  - Banks (3), Hedge Hund (1), Asset Manager (1), ‘Cash Provider’ (1), ‘Asset Manager Investor’ (1)

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1. **Financial Institutions:** Represented by Balance Sheets

Bank

Cash	Deposits
External Assets	LT Funding
Interbank Loans	Interbank Deposits
Reverse Repo	Repo
Tradable Assets	Other
Other	Equity

Hedge Fund

Cash	Repo
Tradable Assets	Equity

Cash Provider

Cash	Liabilities
Reverse Repo	

Asset Manager

Cash	Shares
Tradable Assets	

AM Investors

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2. Financial Contracts:

Informs about:

a) Interconnections between Financial Institutions -> Network, Counterparties

b) (Contingent) Valuation of Balance Sheet Items -> Solvency

c) (Contingent) Cash Flows -> Liquidity

Can act as:

d) ‘Carrier of Contagion’

   i. Interaction between Contagion Channels

      • Amplification, addition or dampening between contagion channels

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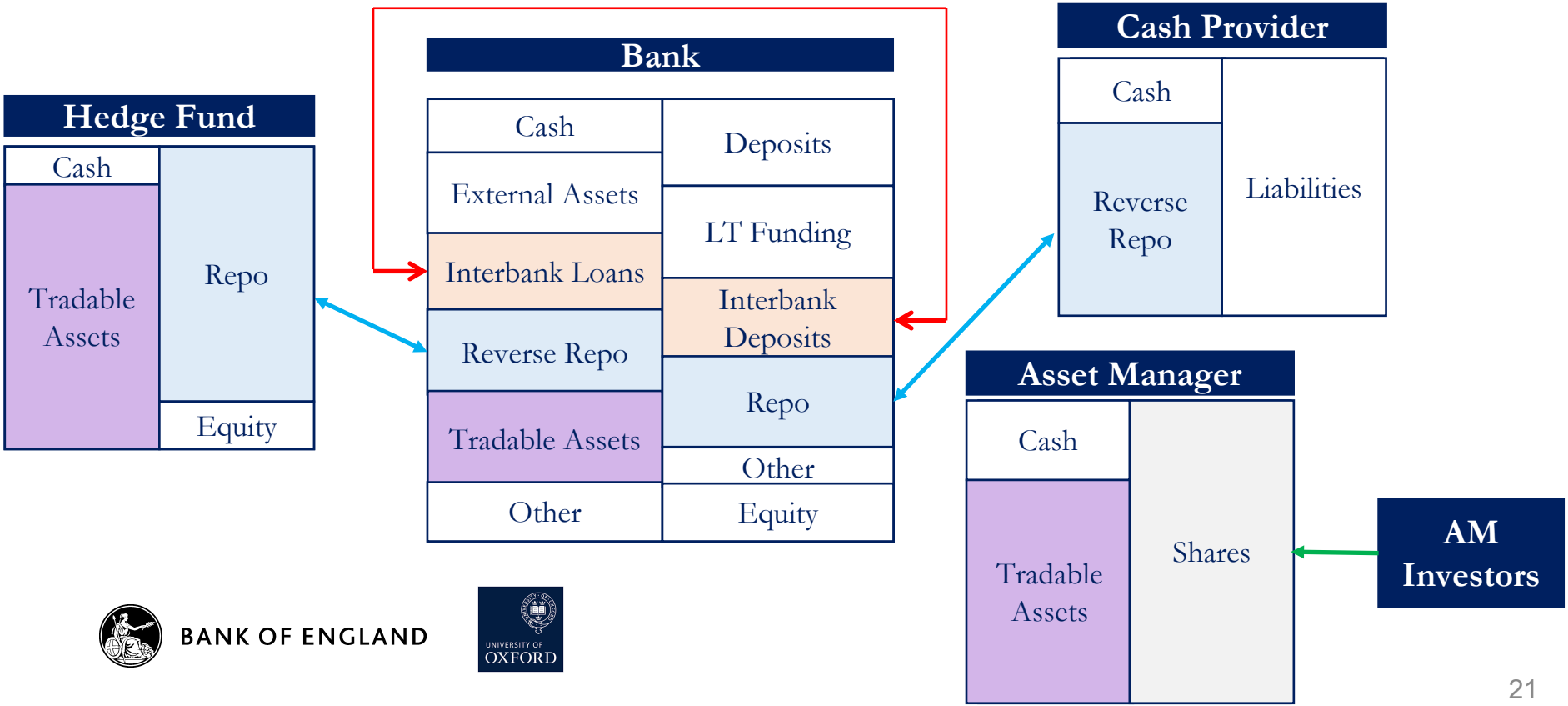
2a) Financial Contracts: Stipulate Interconnections



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2d) Financial Contracts can act as `Carriers of Contagion'*

	Interbank contracts	Repurchase agreements	Tradable assets	Asset manager shares
Funding contagion	✅	✅		✅
Pre- and post-default solvency contagion	✅			
Margin call contagion		✅		
Firesale contagion		✅	✅	

*Alissa Kleinnijenhuis & Thom Wetzer, "Carriers of Contagion" *Working Paper*

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2d) Financial Contracts: Interacting Contagion Channels*

How the interaction between contagion channels arises:

I. Temporally linked

II. Joint set of actions

III. Contingent inputs of financial contracts (valuation or liquidity obligations)

How amplification between contagion channels arises:

The joint effect of contagion channels causes a valuation and/or liquidity shock…

… which causes a financial institution to breach a threshold (*i.e.* constraint)…

... which in turn, non-linearly, causes further valuation and/or liquidity shocks

*Alissa Kleinnijenhuis & Thom Wetzer, “Carriers of Contagion” *Working Paper*

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3. Markets

- Market for price formation of tradable assets (similar to Greenwood et al. 2015)

$$p_a^{t+1} = p_a^t(1 - k_a)Q_a^t \quad , \quad k_a = \frac{1}{D_a}$$

$$Q_a^{t+1} := v_a^{t,S} - v_a^{t,B} = \sum_{i \in \mathcal{F}} [v_{ia}^{t,S} - v_{ia}^{t,B}]$$

- Markets for other financial contracts not yet implemented (working on it!)
  - Eg no option to replace a non-rolled over funding contract with a new one

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4. Constraints

Four types of constraints:

a) Regulatory constraints

b) Contractual Constraints

c) Market-Based Constraints

d) Internal Risk Limits (not considered here)

Constraints can drive behaviour in stress:

- Actions to avoid breaching constraints can contribute to further contagion.
- Default consequences if binding constraints are breached cause further contagion.

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4a) Constraints: Regulatory

- Regulatory constraints we consider
  - Banks
    - Leverage ratio: $\lambda_i^t := \frac{E_i^t}{A_i^t} = \frac{A_i^t - L_i^t}{A_i^t}$, $\lambda_i^t < \lambda^M$ (harder constraint)
    - Liquidity coverage ratio (LCR): $l_i^t = \frac{C_i^{u,t}}{\mathbf{oL}_{it}^{\mathbf{T}}}$, $l_i^t > l^M$ (softer constraint)
    - Net stable funding ratio (NSFR), risk-weighted leverage ratio (RWA), and other constraints such as total loss absorbing capacity (TLAC) are computed but not enforced.
- Hedge funds, asset managers, cash providers: no regulatory constraints (yet)

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4b) Constraints: Contractual

Per Type of Financial Contract:

1. Interbank Contracts
   - Obligation to return notional if not-rolled over.
2. Repurchase Agreements
   - Obligation to return notional if not-rolled over, return of collateral.
   - Fulfil margin call: $M_{ij}^t := R_{ij}^t - \Omega_{ji}^t$
   - For Hedge Fund: Leverage Constraint $\lambda_i^{M,t} = 1 - [(1 - h_c^t)\omega_i^{c,t} + \sum_{a \in \mathcal{A}} (1 - h_a^t)\omega_{ia}^t] \ , \ \lambda_i^t < \lambda_i^{M,t}$
3. Common Asset Holdings
4. Asset Manager Shares
   - Obligation to return NAV of shares upon redemption.

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4c) Constraints: Market-Based

- Before regulatory constraints bind typically market constraints already bind
  - Eg the market stops funding a bank before its reaches its regulatory minimum leverage ratio.

- The cash provider sets market-based constraints in our model:
  - Sets haircuts for repurchase agreements (bank passes these haircuts on to hedge funds) (similar to Bookstaber 2014)
  - Reduces (repo) funding to bank if its solvency or liquidity position becomes sufficiently weak .

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5) Behaviour

- *Behaviour is uncertain*. As such we have to make **assumptions on behaviour**. The outcome of the stress test explicitly ***conditional on the behaviour chosen***.
- What do we know? Behaviour under stress is driven by constraints.
    - Ie financial institutions act to avoid breaching constraints to avoid defaulting; or cause actions when defaulted (after breaching binding constraints).
- Approach: for now, we generalise upon the systemic risk literature:
    - Agents are passive and only act to avoid breaching binding constraints; or cause actions when defaulted (after having breached a binding constraint)
        - Examples from the literature: Leverage targeting (to avoid breaching minimum leverage), Interbank Exposure Losses after default (after minimum leverage breached).

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II. Multi-Layered Bi-Partite Network

Step 1: Initialisation *(use building blocks: (1) financial institutions, (2) financial contracts)*

- **Nodes:**

First set	Second set
Financial institutions	Common asset holdings

- **Edge types (with each type creating a layer):**

1	Interbank contracts
2	Repurchase agreements
3	Common asset holdings (indirect links)
4	Asset manager share holdings

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II. Multi-Layered Bi-Partite Network

Step 2: Simulate the **evolution** of the network – which also requires us to use building blocks: *(3) markets, (4) constraints, (5) behaviour*.

Start stress test by applying **initial set of adverse shocks**, as in micro-prudential stress test, and **run the simulation**:

1	Institutions update balance sheets and relevant metrics
2	Institutions assess whether they need to take any actions, and choose which ones to take
3	The actions (e.g. raising haircuts, deleveraging) are executed
4	Agents evaluate the impact of actions on markets
5	Where necessary, agents respond to this impact and to actions taken by other participants
6	Move to the next timestep

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III. Generating Outputs

Goal of stress testing 1)-3) -> Outputs of model in framework give us 1)-3):

1. Assess systemic risk
2. Identify sources of systemic risk
3. Evaluate policies to mitigate systemic risk

Intermediate outputs:

- Plot any intermediate output to **understand the dynamics** and **generate a story**.

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Conclusion

We propose a **framework** for system-wide stress simulations, and we produce a **stylised example** that illustrates how this framework captures multiple channels of contagion across sectors.

We initialise a **multi-layered network** and **simulate its evolution**.

We can consider **interacting sectors**
contagion channels
constraints

We can run **policy experiments** and ask **“what if” questions.**

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