# Taking regulation seriously: Fire sales under solvency and liquidity constraints

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# Disclaimer

The views expressed are those of the authors only and do not necessarily reflect those of the Bank of England or Norges Bank.

# Motivation

*“During the early ‘liquidity phase’ of the financial crisis that began in 2007, many credit institutions, despite maintaining adequate capital levels, experienced significant difficulties because they had failed to manage their liquidity risk prudently... (Such) credit institutions were then forced to liquidate assets in a fire-sale which created a self-reinforcing downward price spiral and lack of market confidence triggering a solvency crisis."*

(European Commission, 2015)

# Motivation

- Liquidity issues during the crisis
- Multiple regulatory constraints
- Macroprudential stress tests

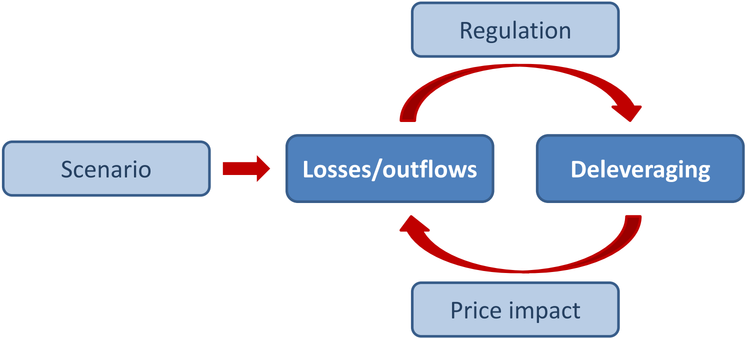
# Objectives

- Build a quantitative model of fire sales to assess the interaction between liquidity and solvency constraints that banks simultaneously face.
- Which types of financial shocks and regulatory requirements combine to produce fire sales?
- How do banks optimally liquidate their portfolios when they are forced to do so?

# Literature review

- **Fire-sale models:**
  [Greenwood et al., 2015], [Cont and Schaanning, 2017], [Duarte and Eisenbach, 2013]
- **Constraints and optimal deleveraging:**
  [Cecchetti and Kashyap, 2016], [Braouezec and Wagalath, 2016]
- **Macro-stress tests:**
  [Dees and Henry, 2017], [Bank of England, 2017], [Bardoscia et al., 2017], [Fique, 2017], [Puhr and Schmitz, 2014], [Calimani et al., 2017]

# Model overview



# Bank balance sheets

- **Marketable securities** $M_{i,k}, k = 1...310$ and $i = 1...7$
  Bonds and equity holdings that are held for trading, available for sale, or designated at fair value through profit or loss.
- **Other assets** $O_{i,k}, k = 1, 2$: loans, intangible goods, derivatives and off-balance sheet items, which are **not** available for deleveraging.
- **Cash** or cash-like assets $C_{i,k}, k = 1, 2$.

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- **Cash** or cash-like assets $C_{i,k}, k = 1, 2$.
- **Liabilities** $L_{i,k}, k = 1...12$. These include classic retail customer deposits, institutional deposits, short-term whole-sale funding, and issued debt.
- **Capital** $E_i$.

# Regulatory constraints

- **Risk-weighted Capital Ratio:**

$$CAP^i(A, E) := \frac{E^i}{\rho^\top A^i} \geq REG_{CAP}.$$

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- **Liquidity Coverage Ratio:**

$$LCR^i(A, C, L) := \frac{\lambda^\top M^i + \mathbf{1}^\top C^i}{\omega_{out}^\top L^i - \omega_{in}^\top A^i} \geq REG_{LCR}.$$

# Shocks

We consider three type of shocks:

1. Asset shock ($\epsilon_A$): $A_0^{i,k} = A^{i,k}(1 - \epsilon_A^k)$. (k = 1...314)
2. Funding shock ($\epsilon_L$): $L_0^{i,k} = L^{i,k}(1 - \epsilon_L^k)$. (k = 1..12)
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$$E_0^i = (E^i - \epsilon_A^\top A^i)^+.$$

$$C_0^i = (C^i - \epsilon_L^\top L^i)^+.$$

# Market depth definition

We follow [Cont and Schaanning, 2017] and define the asset $k$ market depth as:

$$\delta_k = c\frac{ADV_k}{\sigma_k},$$

where:

- $ADV_k$ is the average trading volume,
- $\sigma_k$ is the daily volatility,
- $c$ is a scaling parameter close to 0.5 ([Obizhaeva, 2012]).

# Fire-sale losses

Price evolution under fire sales

$$P_{t+1}^{k} = P_{t}^{k}\left(1 - \delta_{k}^{-1}\sum_{i=1}^{N} S_{t}^{i,k}\right),$$

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Two forms of loss:

- Mark-to-market losses

$$\sum_{k=1}^{K} \underbrace{(M_{t}^{i,k} - S_{t}^{i,k})}_{\text{Remaining holdings}} \times \underbrace{\delta_{k}^{-1}\sum_{i=1}^{N} S_{t}^{i,k}}_{\text{Price impact (above)}} .$$

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- Implementation shortfall

$$\frac{1}{2} \sum_{k=1}^{K} S_t^{i,k} \sum_{j=1}^{N} \delta_k^{-1} S_t^{j,k}.$$

# Fire-sale losses

- However banks only internalise the price impact of their own sales:

$$\frac{\mathbf{S_t^{i,k}}}{\delta_k}$$

- and not the effects of sales by other banks:

$$\frac{\sum_{i=1}^{N} S_t^{i,k}}{\delta_k}.$$

# Banks' deleveraging

- When necessary, banks use the sale proceeds to retire liabilities ($\mathbf{R^i}$) in order to improve their leverage and/or LCR constraints.
- We require banks to use the proceeds to retire liabilities in a pecking order of most to least harshly treated by the LCR.

# Bank optimisation problem: Minimize liquidation losses

$$\min_{\mathbf{S^i},\mathbf{R^i}} (M^i - \frac{1}{2} S^i)^\top (\frac{S^i}{\delta}),$$

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$$\min_{\mathbf{S^i},\mathbf{R^i}} (M^i - \frac{1}{2} S^i)^\top (\frac{S^i}{\delta}),$$

subject to the constraints

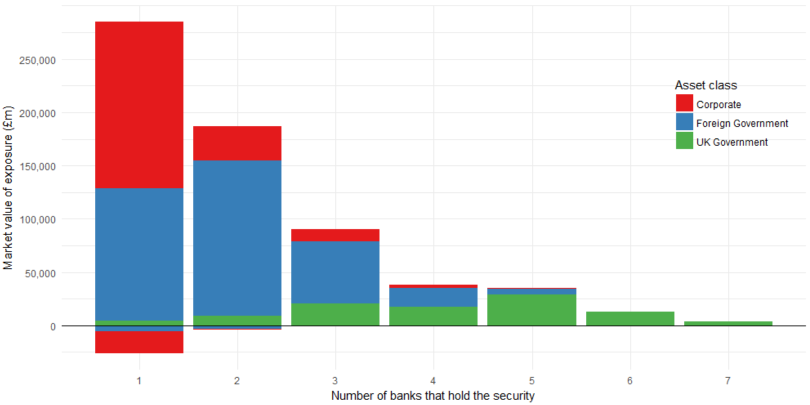
$$\begin{aligned} CAP^i(A, E; \mathbf{S}) &\geq REG_{CAP} \\ LEV^i(A, C, E; \mathbf{S}, \mathbf{R}) &\geq REG_{LEV} \\ LCR^i(A, C, L; \mathbf{S}, \mathbf{R}) &\geq REG_{LCR} \\ CASH^i(A, C; \mathbf{S}, \mathbf{R}) &\geq 0. \end{aligned}$$

# Calibration

- **Balance sheet data** taken from regulatory returns (COREP and FINREP) and Bank of England stress test data.
- **Regulatory weights** based on Basel guidance, European legislation and firms' annual statements.
- **Regulatory ratios & constraints** taken from regulatory returns.
- **Market depths** based on national authorities' published statistics on average trading volumes and S&P price indices for government bonds, and BoAML prices and oustanding volumes for corporate bonds.

# Portfolio overlaps

**Figure 1:** Market value of overlapping portfolio by asset class (ISIN level)



# Marketable asset categories and regulatory weights

| Asset | Exposure | LCR haircut | Risk weight |
|---|---|---|---|
| | Govts and CBs | 0 | 0 |
| | | 15 | 20 |
| Bonds | Financials | 0 | 0 |
| | | 7 | 0 |
| | | 15 | 20 |
| | | 25 | 35 |
| | | 30 | 35 |
| | | 35 | 35 |
| | | 50 | 50 |
| | | 100 | 100 |
| | Non financials | 100 | 100 |
| Equities | | 50 | 100 |
| | | 100 | 250 |

# Stress scenarios

We consider three scenarios:

1. Asset shock ($\epsilon_A$): Bank of England 2017 Stress scenario and shocks of increased intensity.
2. Funding shock ($\epsilon_L$): Depositor run (20%, 40% and 60% deposit outflows).
3. Combined asset and funding shock: Bank of England 2017 Stress scenario and 20% deposits outflows.

# Asset shock from the 2017 Bank of England stress test

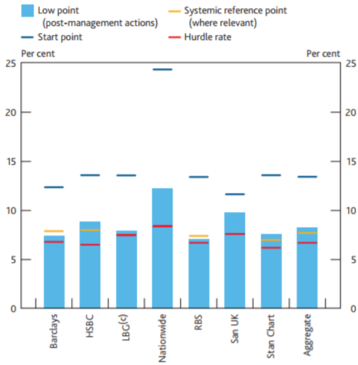



**Figure 1:** Projected CET1 capital ratios in the stress scenario

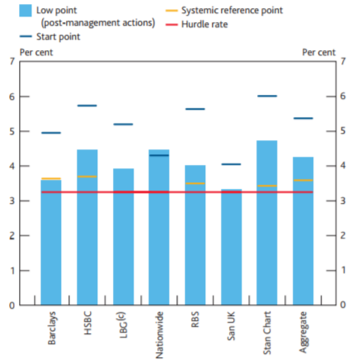



**Figure 2:** Projected Tier 1 leverage ratios in the stress scenario

# Asset shock

- Risk-weighted capital requirements tend to be more tightly binding than leverage constraints.
- Banks constrained by risk-weighted capital constraints sell on average more illiquid assets, and in larger amounts, than when constrained by the leverage ratio.
- The size of unexpected losses, which are not internalized by banks, can be as important as the size of expected losses.

# Asset sales: leverage ratio only

## Proposition

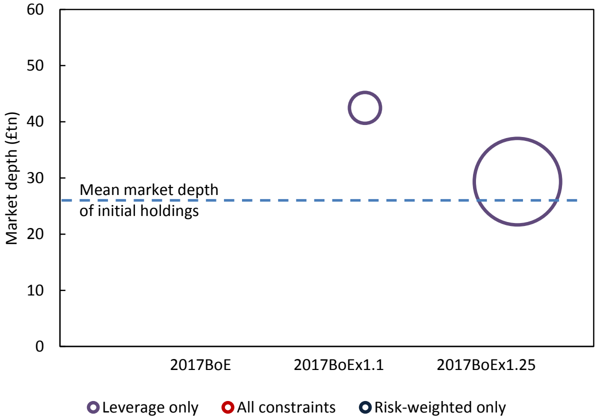
*Under a leverage constraint only, the optimal solution is to sell assets sequentially in decreasing order by the ratios:*

$$\frac{\delta_k}{M^{i,k}}$$

*until the constraint is fulfilled, or the bank runs out of marketable assets to delever*[1]*.*

[1] *Reverse Stress Testing* - Michel Baes, Rama Cont ad Eric Schaanning

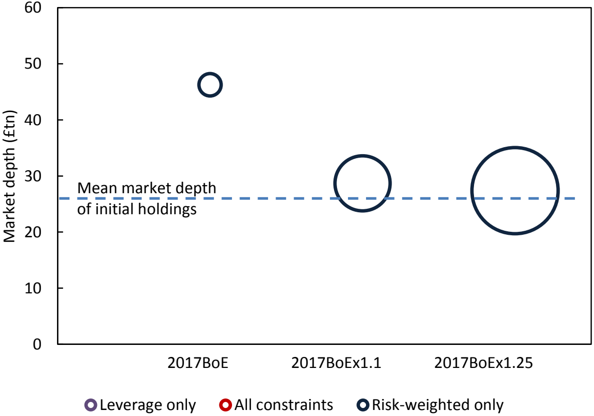
# Asset sales: leverage ratio only



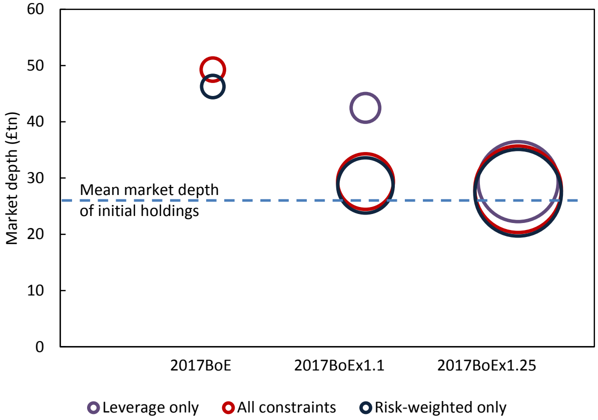
# Asset sales: capital ratio only

- Banks face a trade-off between minimizing the price impact of asset sales and complying with the capital ratio constraint.
- They need to take into account the market liquidity and the risk-weight of each asset.
- Optimal solution:
  - two assets: [Braouezec and Wagalath, 2016],
  - multiple assets: work in progress.

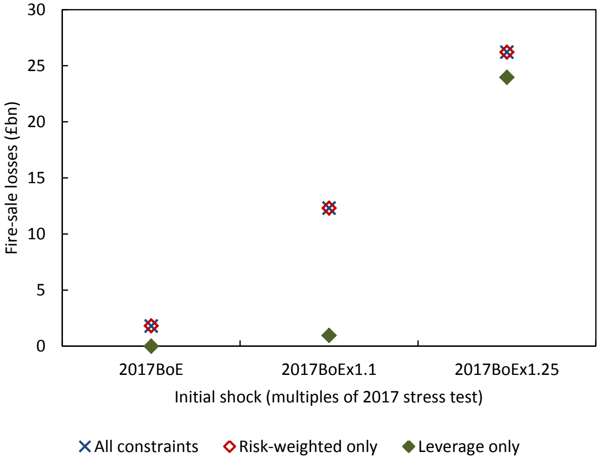
# Asset sales: capital ratio only



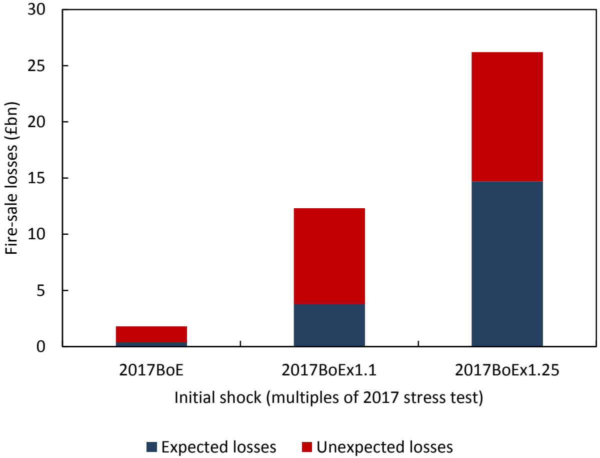
# Asset sales: all constraints



# Fire-sale losses



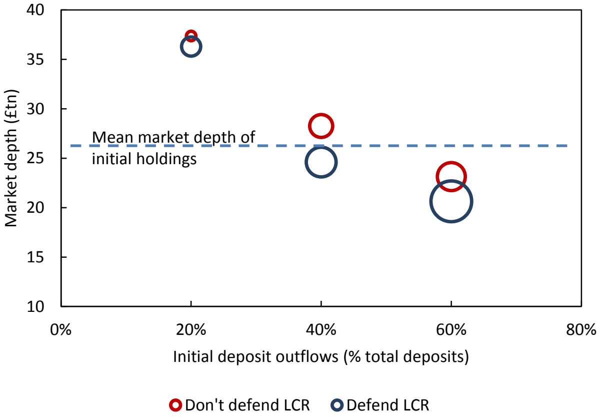
# Fire-sale losses: decomposition



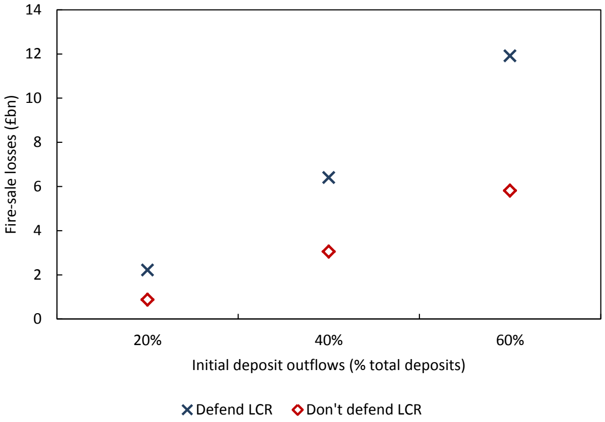
# Funding shock: deposit outflows

- Banks prefer to use cash and sell highly liquid assets first to minimise losses.
- However, as the shock becomes larger, banks are forced to sell less liquid assets.
- When banks defend their LCRs to keep them above 100%, they need to sell less liquid assets in larger amounts.
- Hence fire-sale losses are significantly larger relative to the case when banks do not defend their LCRs.

# Asset sales


40
35
30
25
20
15
10
Market depth (£tn)
Mean market depth of
initial holdings
0%
20%
40%
60%
80%
Initial deposit outflows (% total deposits)
Don't defend LCR
Defend LCR

# Fire-sale losses



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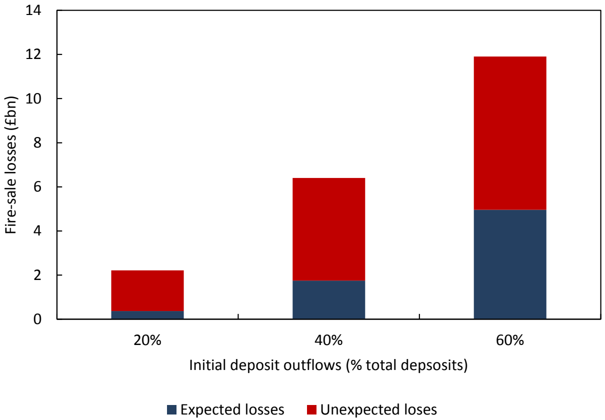
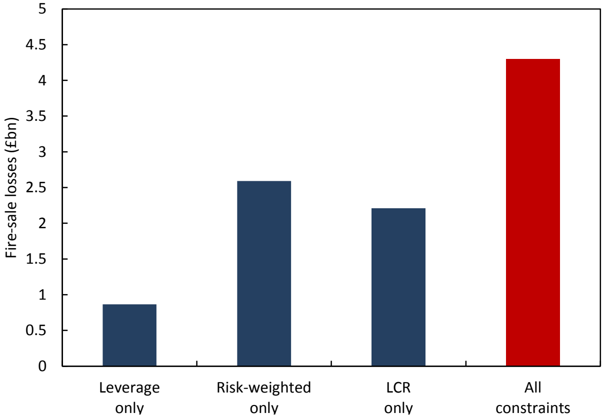


# Asset and Funding shocks



# Conclusions

- Both risk-weighted capital and liquidity constraints can become binding and generate significant fire sales losses, by incentivising sales of larger amounts of less liquid assets.
- Models that only account for a leverage constraint might then under-estimate fire sale losses.

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- Both risk-weighted capital and liquidity constraints can become binding and generate significant fire sales losses, by incentivising sales of larger amounts of less liquid assets.
- Models that only account for a leverage constraint might then under-estimate fire sale losses.
- Unexpected fire sales losses, e.g. losses due to deleveraging by other banks, can be larger than banks' expected losses from their own sales.
- Relaxing banks' regulatory constraints during stress may be a possible mitigating action to avoid fire sales. For example, allowing banks to draw down their LCR.

# Thank you

# Regulatory constraints when deleveraging

Capital ratio:

$$CAP^i(A, E; S) := \frac{(E^i - (M^i - \frac{1}{2}S^i)^\top p)^+}{\rho_M^\top [(M^i - S^i) \circ (\mathbf{1} - p)] + \rho_O^\top O_0^i},$$

Leverage ratio:

$$LEV^i(A, C, E; S, R) := \frac{(E^i - (M^i - \frac{1}{2}S^i)^\top p)^+}{(M^i - S^i)^\top (\mathbf{1} - p) + C^i + (S^i)^\top (\mathbf{1} - \frac{1}{2}p) - \mathbf{1}^\top R^i + O_0^i}.$$

Liquidity Coverage ratio:

$$LCR^i(A, C, L; S, R) := \frac{\lambda^\top \left[(M^i - S^i) \circ (\mathbf{1} - p)\right] + \mathbf{1}^\top C^i + (S^i)^\top (\mathbf{1} - \frac{1}{2}p) - \mathbf{1}^\top R^i}{\omega_{out}^\top (L^i - R^i) - \omega_{in}^\top [(M^i - S^i) \circ (\mathbf{1} - p)]}.$$

Baes, M., Cont, R., and Schaanning, E. (2018).
Reverse stress testing.
Working paper.

Bank of England (2017).
Stress testing the uk banking system:2017 results.

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.

Braouezec, Y. and Wagalath, L. (2016).
Risk-based capital requirements and optimal liquidation in a stress scenario.
Review of Finance, page rfw067.

Calimani, S., Hałaj, G., Żochowski, D., et al. (2017).
Simulating fire-sales in a banking and shadow banking system.
Technical report, European Systemic Risk Board.

Cecchetti, S. and Kashyap, A. (2016).
What binds? interactions between bank capital and liquidity regulations.

Cont, R. and Schaanning, E. (2017).
Fire sales, indirect contagion and systemic stress testing.
Norges Bank Working Paper.

Dees, S. and Henry, J. (2017).
Stress-test analytics for macroprudential purposes: Introducing stamp€.
SATELLITE MODELS, page 13.

Duarte, F. and Eisenbach, T. M. (2013).
Fire sale spillovers and systemic risk.
Federal Reserve Bank of New York Staff Report, 645.

Fique, J. (2017).
The MacroFinancial Risk Assessment Framework (MFRAF), Version 2.0.
Bank of Canada.

Greenwood, R., Landier, A., and Thesmar, D. (2015).
Vulnerable banks.
Journal of Financial Economics, 115(3):471 – 485.

Obizhaeva, A. A. (2012).
Liquidity estimates and selection bias.
Working Paper.

Puhr, C. and Schmitz, S. W. (2014).
A view from the top: The interaction between solvency and liquidity stress.
Journal of risk management in institutions, 7(1):38–51.