Liquidity at Risk

Joint Stress Testing of Liquidity and Solvency Risk

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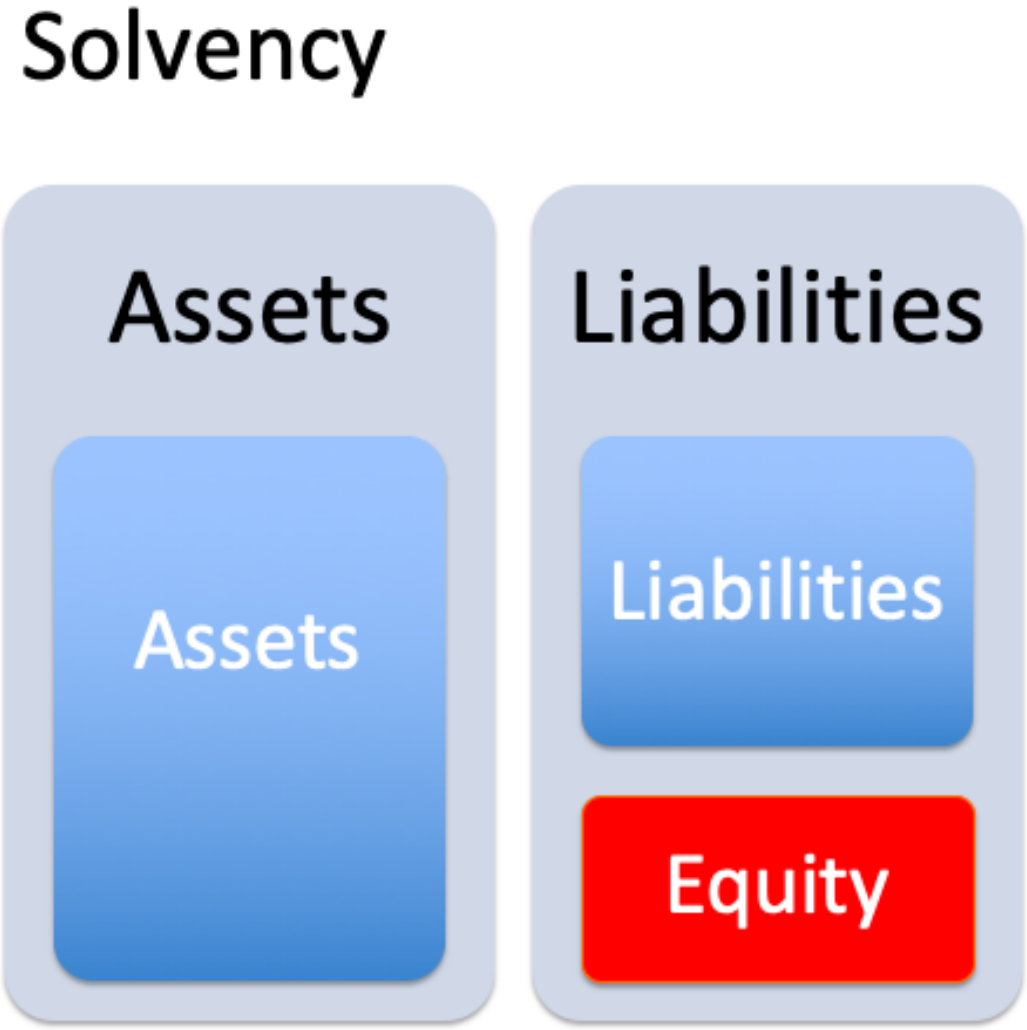
Solvency stress testing



Solvency condition:

Assets > Liabilities

Capital =
Assets - Liabilities

Solvency under stress scenario:

Δ Assets+ Equity>0

Solvency Risk

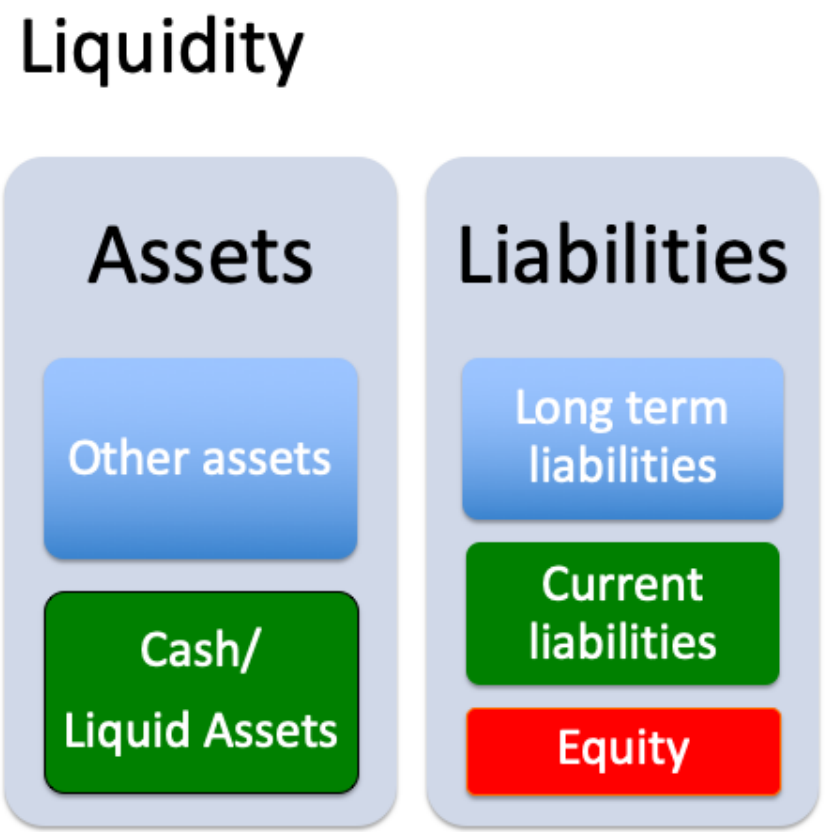
- Solvency risk is driven by the difference in firm's asset values and its liabilities.
- Bank stress testing, which has become a key tool for bank supervisors, has also mainly focused on solvency risk.
- Regulation of insurance companies also focused on solvency risk (Solvency II, Swiss Solvency test).
- However, solvency risk does not give the full picture – we have spectacular failures of SIFIs due to lack of liquidity:
  - Bear Stearns held excess capital at the time of its default.
  - AIG, which failed to fulfill large payment triggered by a downgrade, was not insolvent at the time of failure.
  - Banco Popular, which failed through a lack of liquidity in 2017, displayed a capital ratio 6.6% in the 2016 EBA *adverse* scenario.

Liquidity Risk and Default

- **Liquidity risk**: failure to meet a short-term payment obligation.
  - *Default of payment* is the legal definition of default.
  - Inherent risk to instability in short-term funding (e.g. debt roll-over risk) and cash-flows (e.g. variation margin).
- Supervision and regulation of bank liquidity:
  - *Liquidity Coverage Ratio (LCR)*: banks to hold liquidity provision for expected outflows over 30-day time horizon.
  - *Net Stable Funding Ratio (NSFR)*: limits over-reliance on short-term wholesale funding and aims to increase funding stability.
  - Liquidity stress testing: e.g. ECB's 2019 sensitivity analysis of liquidity risk (LiST) typically done **separately** from solvency stress testing.

Liquidity Risk

Defining **liquidity** requires the introduction of a **horizon** *T*.
We use the term 'Maturing (or Current) Liabilities' for contractual and projected/ anticipated liabilities over this horizon.



- Liquidity condition:

Liquid Assets > Current Liabilities

Liquidity buffer= Liquid Assets - Current Liabilities

- If

Liquid Assets < Current Liabilities then firm needs to raise liquidity in the short term.

In current stress testing approaches, liquidity and solvency stress tests are conducted separately, with little or no interaction between them:

Euro area	Japan	Switzerland	United States
SSM ST: does not apply. **MPE ST / MTD ST:** interaction between solvency and liquidity is to some extent incorporated via additional shocks to funding costs that endogenously respond to solvency conditions. This is also formally embedded in the specific set of liquidity ST modelling tools (with a direct impact of solvency ratios on funding cost and access).	**BoJ ST:** despite efforts by the BoJ to incorporate liquidity risks in stress scenarios, the BoJ ST currently does not capture liquidity risk or the interaction between liquidity and credit risk. The BoJ has conducted tailored event scenarios where specific liquidity constraints in USD funding are examined. However, it would be difficult to say that the current model setup fully incorporates a transmission mechanism where liquidity risk and credit risk play an important role, and this is an area for further improvement. **JFSA ST:** the liquidity ST is conducted independently of the solvency ST. JFSA takes a bottom-up approach by using individual bank-level data in order to assess liquidity risk. It is mainly a tool for microprudential risk assessment, but is also used for financial stability risk assessments for a macroprudential perspective.	**BBA-LB/BBA-DFB:** only the reaction of funding spreads to changing solvency conditions is considered. The possibility of explicitly modelling the interaction of solvency and liquidity aspects is currently being explored in the form of network analyses. Liquidity stress tests are conducted separately. The cost of closing liquidity gaps may be integrated in the solvency stress test. However, this is not applied on a regular basis. **FINMA ST:** liquidity stress testing is covered in a separate stress testing exercise. However, banks are also requested to calculate the impact on net stable funding ratios based on the FINMA scenarios. Specific B/S roll views are applied to provide a conservative view in stress (constant B/S for capital vs shrinking B/S for liquidity).	**DFAST/CCAR:** liquidity stress testing is conducted independently of solvency stress testing. In 2012, the Federal Reserve launched CLAR for LISCC banks. Similar to CCAR, CLAR is an annual horizontal assessment, with quantitative and qualitative elements, overseen by a multidisciplinary committee of liquidity experts from across the Federal Reserve. In CLAR, supervisors assess the adequacy of LISCC portfolio firms' liquidity positions relative to their unique risks and test the reliability of these firms' approaches to managing liquidity risk. CLAR provides a regular opportunity for supervisors to respond to evolving liquidity risks and firm practices over time.

Patrizia Baudino, Roland Goetschmann, Jérôme Henry, Ken Taniguchi and Weisha Zhu (2018) Stress-testing banks – a comparative analysis

The Liquidity-Solvency Nexus

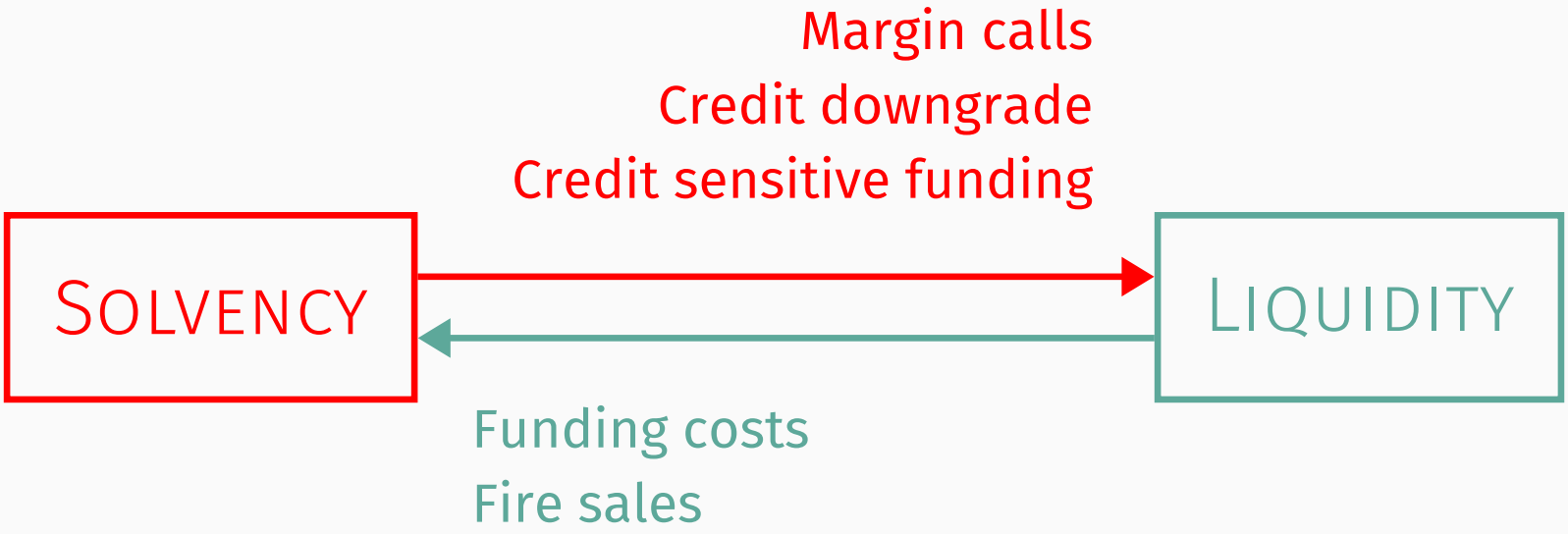
Solvency and liquidity cannot be modeled independently, but current credit risk models and stress testing approaches do not capture their interaction adequately.

- Empirical evidence for the solvency-liquidity nexus:
  - Pierret (2015): increased solvency risk leads to liquidity problems due to credit runs and cost of asset liquidation.
  - Brunnermeier et al. (2019): firms with higher capital experienced lower outflow during the German crisis of 1931.
  - Schmitz et al. (2019): evidence on the empirical relationship between bank solvency and funding costs.
  - Du et al. (2015): empirical evidence that credit quality affects the volume but not the price of available short-term funding.
- But limited theoretical models, mostly on debt rollover failure:
  - Bank run models: link run probability with firm solvency (Diamond and Rajan, 2005; Allen and Gale, 1998; Rochet and Vives, 2004).
  - Morris and Shin (2016), Liang et al. (2013): illiquidity component of credit risk.
  - Liquidity feedback effects (Kapadia et al., 2013).

Addressing the Liquidity-Solvency Nexus in stress tests

- **Objective**: develop a consistent framework for joint stress testing of liquidity and solvency.
- Model should address the key mechanisms through which liquidity and solvency interact:
  - Variation margin requirements: transformation of solvency risk into liquidity risk (Cont, 2017).
  - Credit sensitive liabilities.
  - Costs of liquidity provision.
- Concept of **Liquidity at Risk**: liquidity resources required for a financial institution conditional on a stress scenario.
- Quantitative tool (online app) for assessing the impact on liquidity of a stress scenario defined in terms of 'solvency' shocks to balance sheet components (assets/liabilities).

The Liquidity-Solvency Nexus



Balance Sheet Representation

To capture liquidity-solvency nexus we need a representation of the balance sheet which distinguishes balance sheet components according to their interaction with solvency and liquidity.

<table>
<tr><th>Assets</th><th>Liabilities and equity</th></tr>
<tr><td>Illiquid/encumbered assets:
(i) Subject to margin requirements, I
(ii) Not subject to margin requirements, J</td><td>Maturing liabilities, S</td></tr>
<tr><td>Marketable unencumbered assets:
(i) Subject to margin requirements, M
(ii) Not subject to margin requirements, N</td><td rowspan="2">Other liabilities, L</td></tr>
<tr><td>Cash/Liquid assets, C</td><td rowspan="2">Equity, E</td></tr>
</table>

Table 1: Stylised balance sheet of a financial institution.

Balance Sheet Dynamics

Evolution of balance sheet components following a shock to asset values:

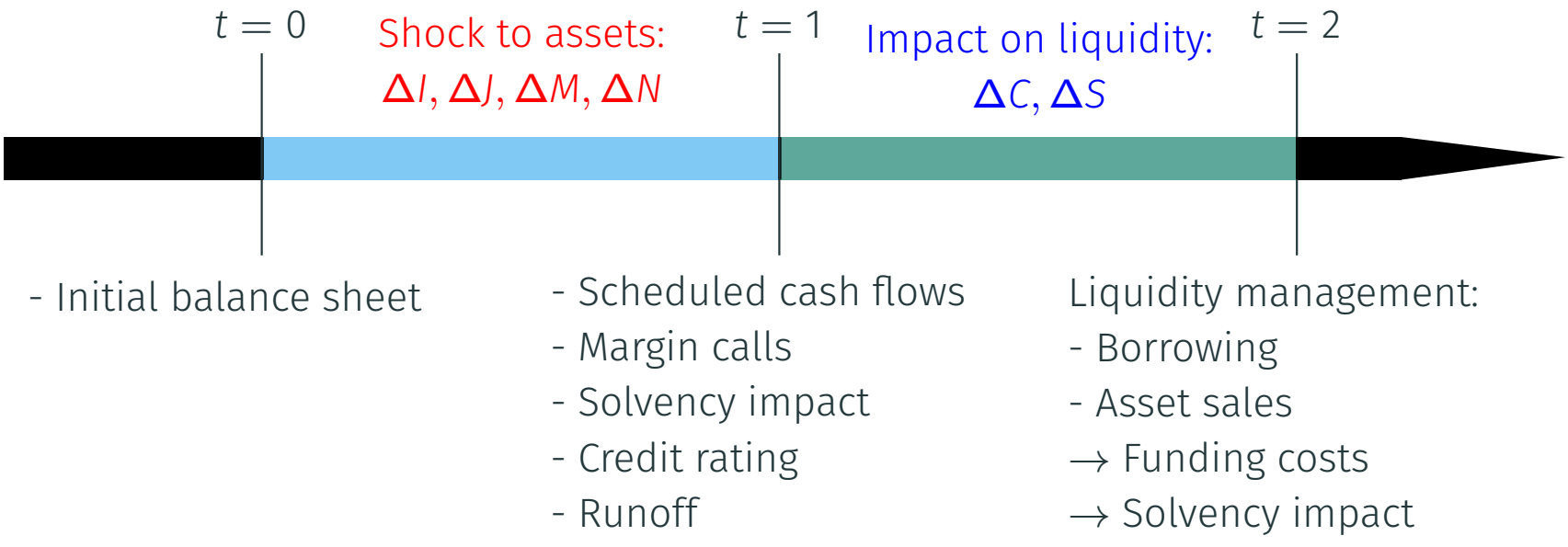
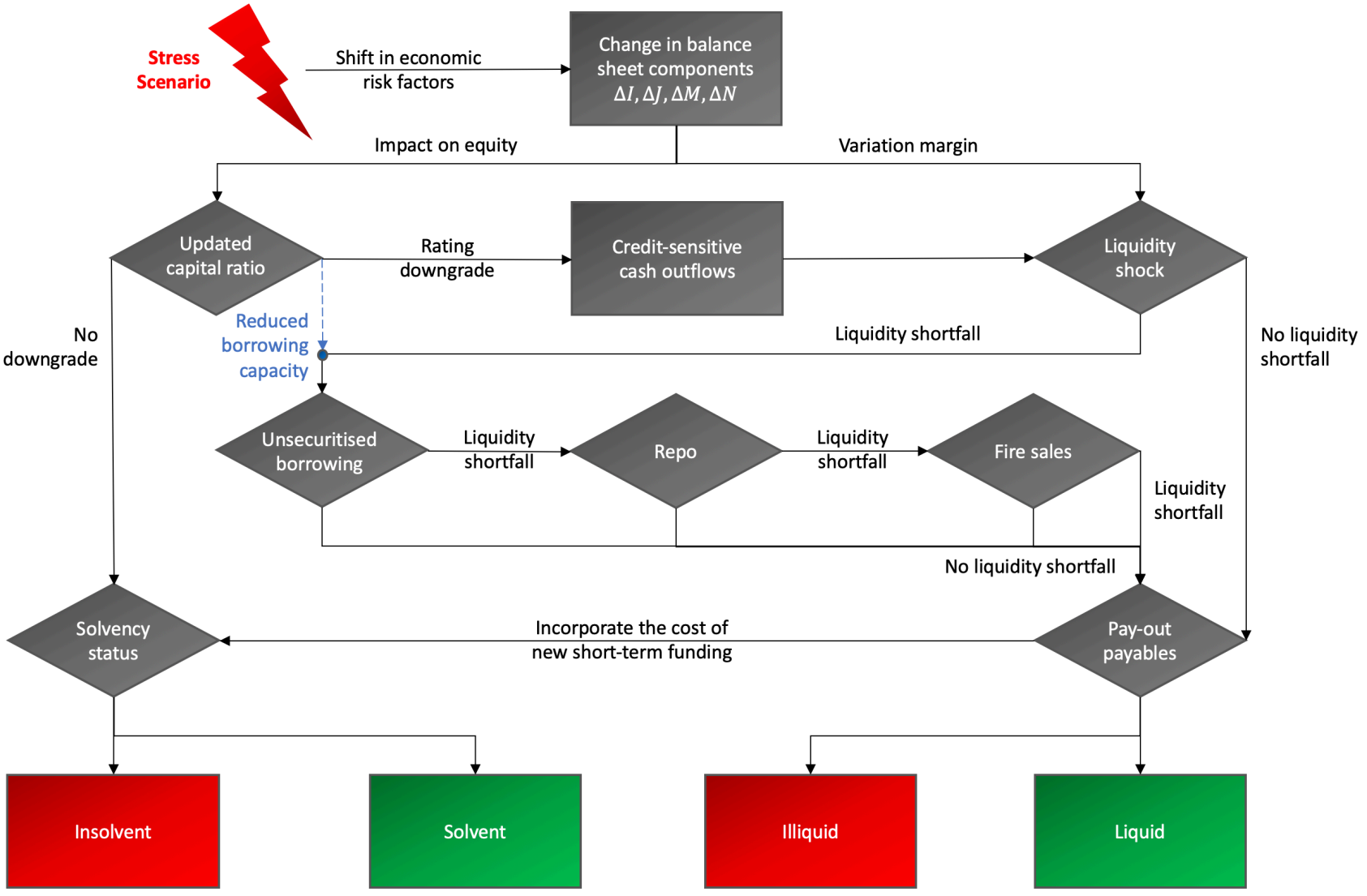


Figure 1: Evolution of balance sheet components.

Overview of methodology



Stress Scenarios and Direct Solvency Impact

- **Stress scenarios** are defined in terms of shifts to risk factors (e.g. GDP, interest rates, equity prices). We describe stress scenario in terms of shocks $\Delta X = (\Delta X_1, .., \Delta X_d)$ to some risk factors X_k, for $k = 1, \ldots, d$.
- **Direct impact on solvency:** denoting by $\partial_k M$ the sensitivity of balance sheet component M to risk factor X_k, we have

$$\Delta M = M_1 - M_0 = \sum_{k=1}^{d} \partial_k M . \Delta X_k = \partial M . \Delta X,$$

  and similarly for other balance sheet items I, J, N.
- The impact on equity is $E_1 = E_0 + \Delta I + \Delta J + \Delta M + \Delta N$.

Liquidity Impact

Obligations coming due at $t = 2$ include four components.

1. Unconditional **liabilities maturing** at $t = 2$ denoted by S_0.
2. **Scheduled Cash Outflows (SCO)**: e.g. contractual cash-flow obligations (interest payments on debt, operating costs), projected outflows from non-maturing liabilities, and estimated drawdowns from undrawn credit and liquidity lines.
3. **Contingent liquidity risks**: a decrease in asset values subject to variation margin leads to margin payments that add to maturing liabilities $\Delta S = (\Delta I)^- + (\Delta M)^-$, whereas increase lead to cash inflows at $t + 2$: $\Delta C = (\Delta I)^+ + (\Delta M)^+$.
4. **Credit risk sensitive funding**: a firm's downgrade generates contingent cash-outflows, denoted by S_D. Note the corresponding reduction in non-maturing debt: $L_1 = L_0 - S_D$.

As a result, conditional on the stress scenarios, maturing liabilities due at $t = 2$ increase to: $S_2 = S_0 + SCO + \Delta S + S_D \mathbb{1}_{\text{downgrade}}$.

Credit Downgrade and Liquidity Shortfall

- **Credit downgrade** occurs if capital ratio or leverage ratio cross a certain threshold, e.g. if

$$\frac{\text{Assets}}{\text{Equity}} = \frac{I_1 + J_1 + M_1 + N_1 + C_0 + SCI}{E_1} > \delta,$$

  where **Scheduled Cash Inflows (SCI)** represent the aggregate value of contractual claims (e.g. interest payments), and maturing assets which are not reinvested.

- The financial institution then faces a **liquidity shortfall** of

$$\lambda = (\underbrace{S_2}_{\text{Payables at t=2}} - \underbrace{(C_1 + \Delta C)}_{\text{Available liquidity}})^+.$$

- When $\lambda > 0$, the institution needs to raise additional liquidity.

Mitigating Actions: Sources of New Short-Term Funding

1. **Unsecuritised borrowing** from short-term creditors:
   - Available to creditworthy institutions at a rate r_U.
   - Limited in volume: $v_U \leq (\delta E_1 - \{I_1 + J_1 + M_1 + N_1 + C_1\})^+ \ /(1 + r_U \delta)$
2. **Repo market**:
   - Borrowing at a rate r_R with provision of general collateral (marketable assets).
   - Volume limited by marketable assets and the associated haircut h: $v_R = (1 - h)(M_1 + N_1)$
3. **Repo with central bank** (if available):
   - Borrowing at a rate $r_{CB} > r_R$ against non-GC assets
   - limited by volume $J_1' < J_1$ of eligible unencumbered non-GC assets and (a large) haircut $H > h$: $v_{CB} = (1 - H)J_1'$
4. **Assets sales** ('fire sales'): liquidation of remaining unencumbered assets, representing a fraction θ of all illiquid assets at a price discount ψ can raise up to $v_S = (1 - \psi)\theta J_1$

Mitigating Actions: Balance Sheet Impact

- These mitigating actions increase the cash buffer at t=2 to

$$C_2 = C_1 + \Delta C + B_U + B_R + \omega(1-\psi)\theta J_1,$$

  where $B_U \leq v_U, B_R \leq v_R$ represents the new unsecuritised, repo funding respectively, and $\omega \in [0,1]$ is the fraction of liquidated eligible illiquid assets in a fire sale. (B_U, B_R, ω are endogenous in the model.)
- The volume of non-maturing liabilities is updated by the amount of new liabilities from unsecured and secured funding:

$$L_2 = L_1 + (1+r_U)B_U + (1+r_R)B_R.$$

- Impact on the equity due to new funding:

$$E_2 = E_1 - r_U B_U - r_R B_R - \omega\psi\theta J_1.$$

- We say the bank is **insolvent** when $E_2 < 0$, while it is **illiquid** when $C_2 < S_2$.

Liquidity at Risk

Consider a stress scenario S defined in terms of shocks to asset values.

Definition (Liquidity at Risk)

The *Liquidity at Risk* associated with a stress scenario is defined as the **net liquidity outflow** arising in this stress scenario, derived from the mechanisms described above.

- Liquidity at Risk is a conditional concept: it quantifies the expected draw on liquidity resources of the bank conditional on the stress scenario being considered.
- Liquidity at Risk measures an expected *net outflow*. This can be compared to the liquidity resources potentially accessible to the bank in the stress scenario, to assess the potential for default.
- Liquidity shortfall
  = Liquidity at Risk - available liquidity resources.

Solvency-liquidity diagram

Case 1: no failure

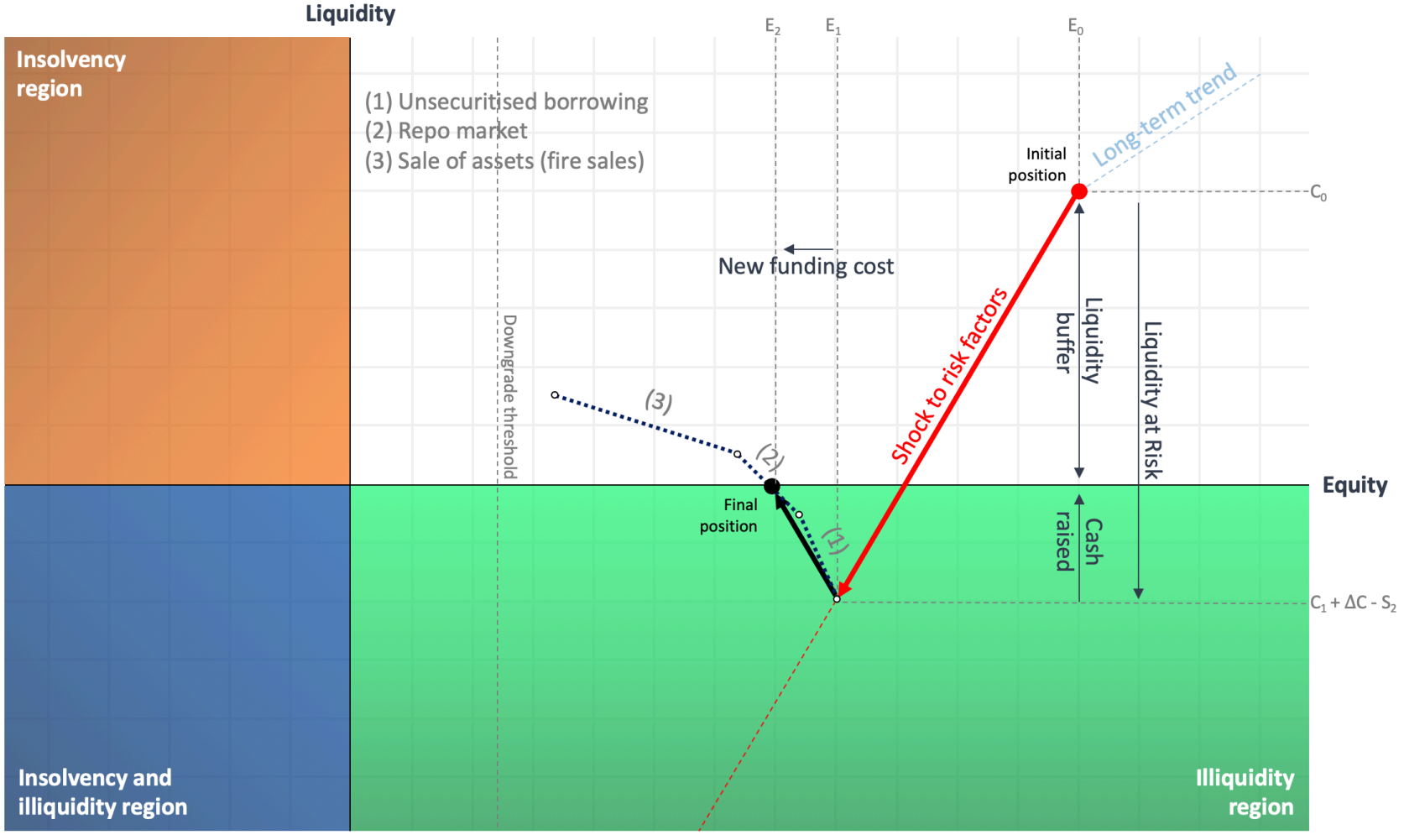


Figure 2: Example of a liquidity-solvency diagram.

Solvency-liquidity diagram

Case 2: illiquid but solvent

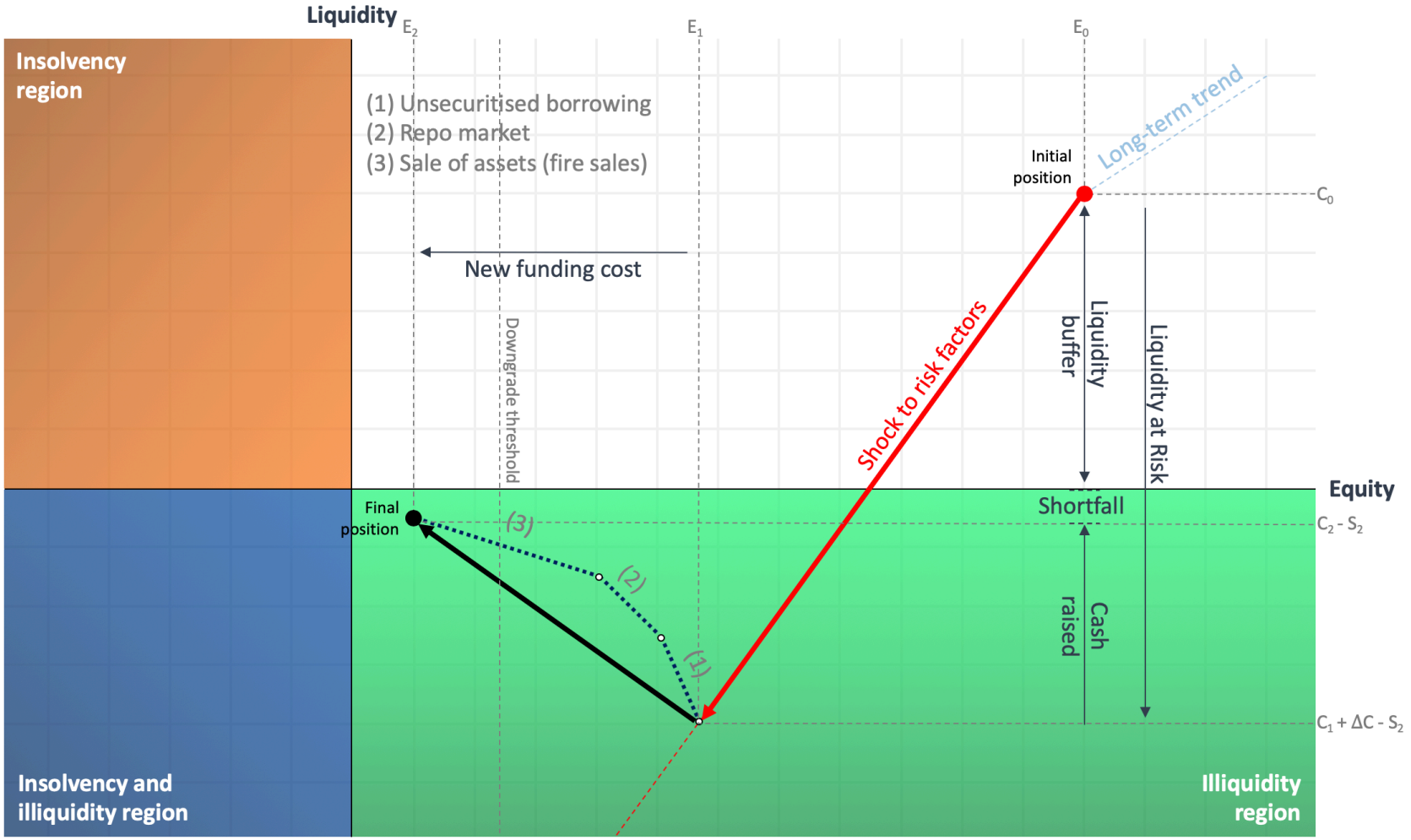


Figure 3: Example of a liquidity-solvency diagram.

Solvency-liquidity diagram

Case 3: liquid but insolvent

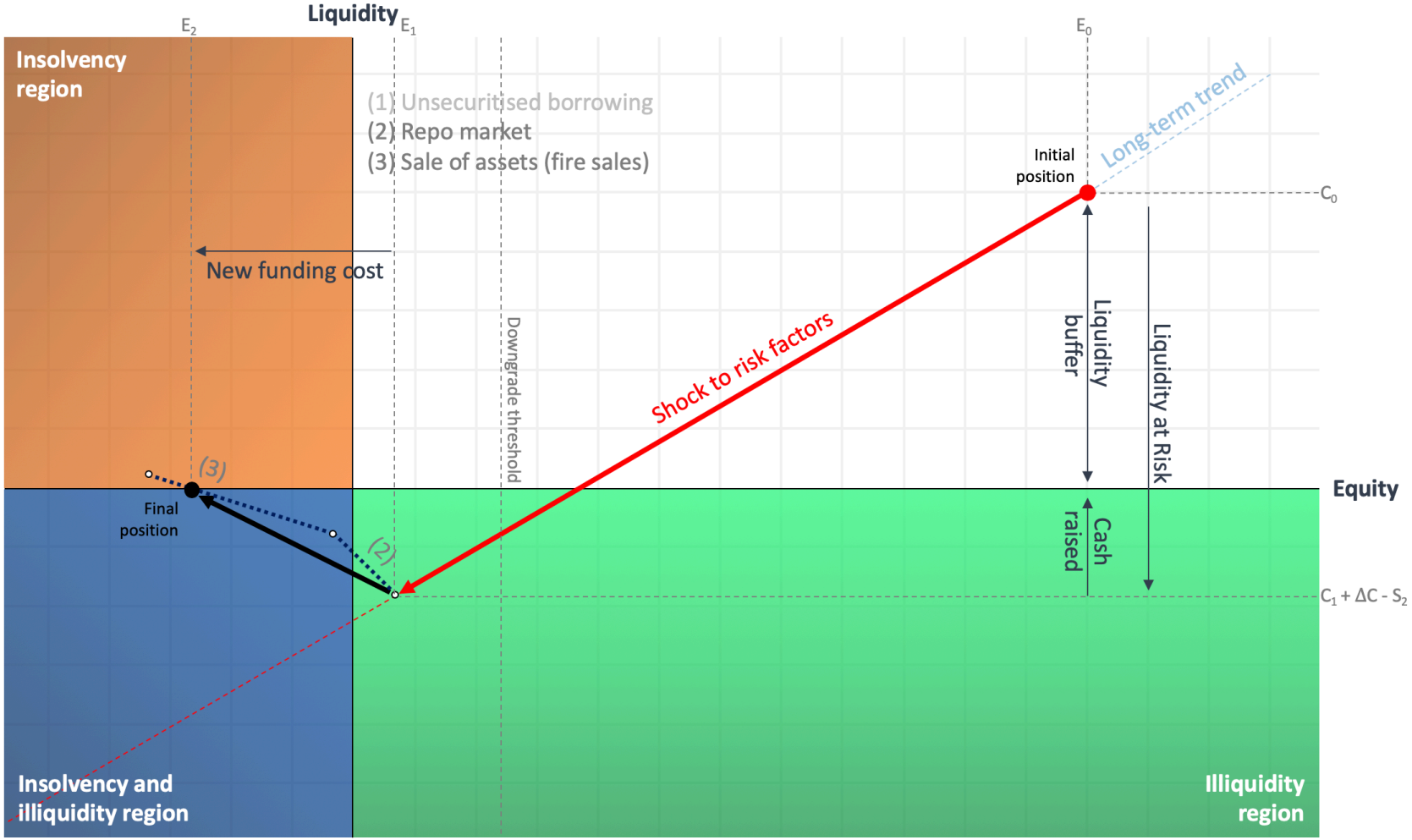


Figure 4: Example of a liquidity-solvency diagram.

Synthetic Example

Assets	Liabilities and equity
Illiquid assets: (i) Subject to VM, $I_0 = 16000$ (ii) Not subject to VM, $J_0 = 134000$	Maturing liabilities, $S_0 = \underline{18000}$
Marketable unencumbered assets: (i) Subject to VM, $M_0 = 43000$ (ii) Not subject to VM, $N_0 = 16000$	Other liabilities, $L_0 = 215000$ (incl. deposits of 130000)
Liquid assets, $C_0 = 38000$	Equity, $E_0 = 14000$ (5.7%)

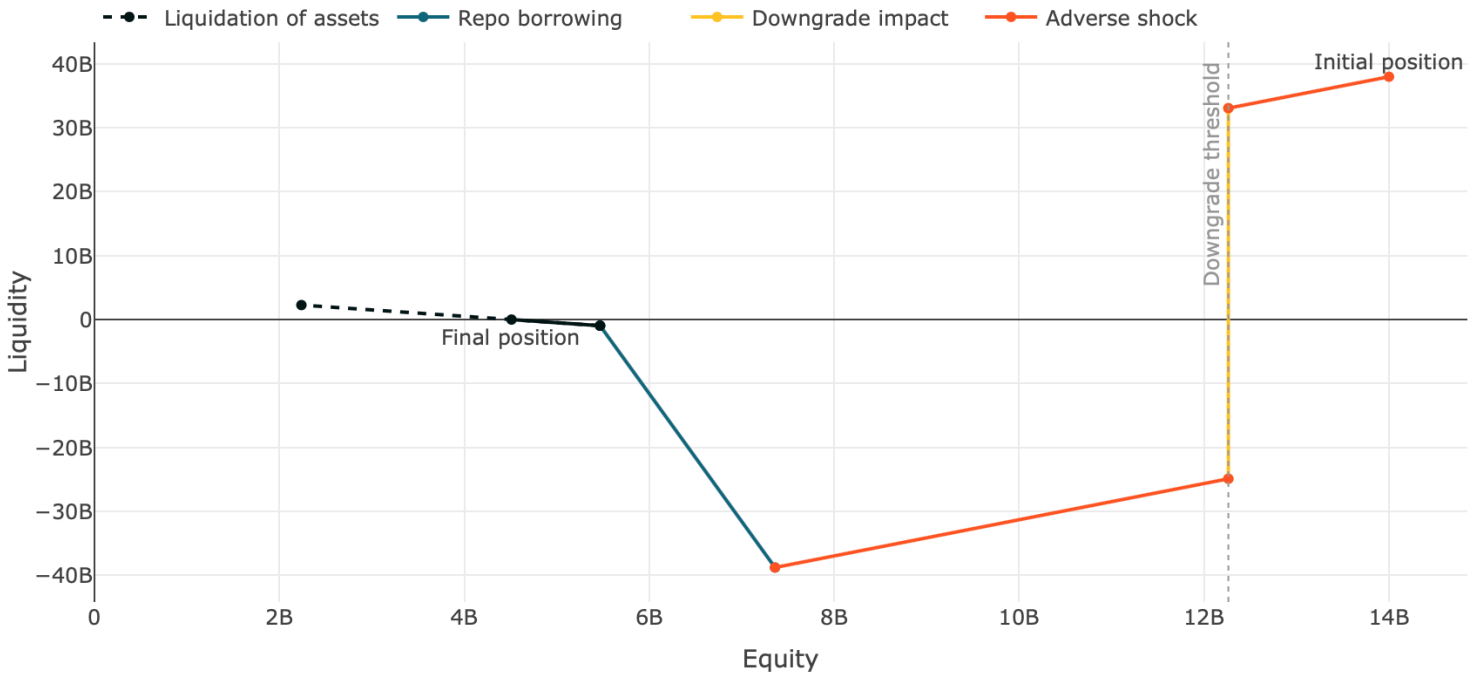
Table 2: A synthetic example of balance sheet for a representative large commercial bank (in \$M). Assume $SCI = \underline{12000}$ M and $SCO = \underline{10000}$ M; $\underline{58000}$ M (45%) depositor runoff on downgrade.

Risk factor	Shift	ΔI	ΔJ	ΔM	ΔN
Interest rates	+200 bps	$\underline{400}$	4800	$\underline{160}$	640
Equity market	-750 bps	$\underline{90}$	0	$\underline{2150}$	400

Table 3: Balance sheet sensitivities in response to a risk factor shift (\$M).

$\underline{\text{Liquidity At Risk}}$ = **\$ 76800 M**, Liquidity shortfall = **\$ 38800 M**

Loss amplification through solvency-liquidity interactions



- Initial equity = **$ 14000 M** (5.7%)
- Equity after adverse shock = **$ 7360 M** (3.0%)
- Funding cost: **$ 1892 M** repo and **$ 958 M** fire sales
- Final equity level = **$ 4510 M** (1.9%) → Loss amplification **43%**

Stress-Test Analysis: Regions of Failure

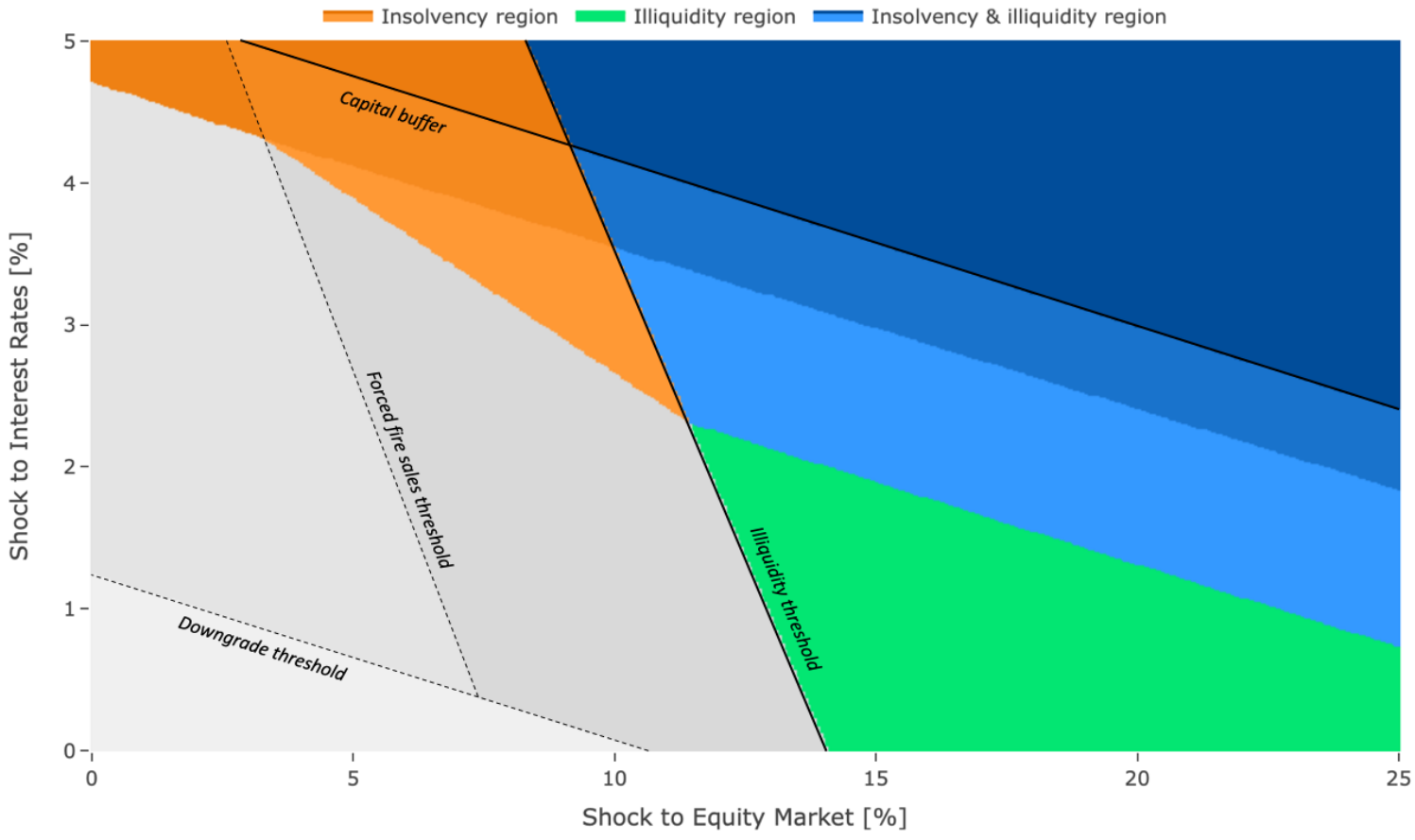


Figure 5: Insolvency and illiquidity regions for a sample bank portfolio.

Loss amplification through solvency-liquidity interactions

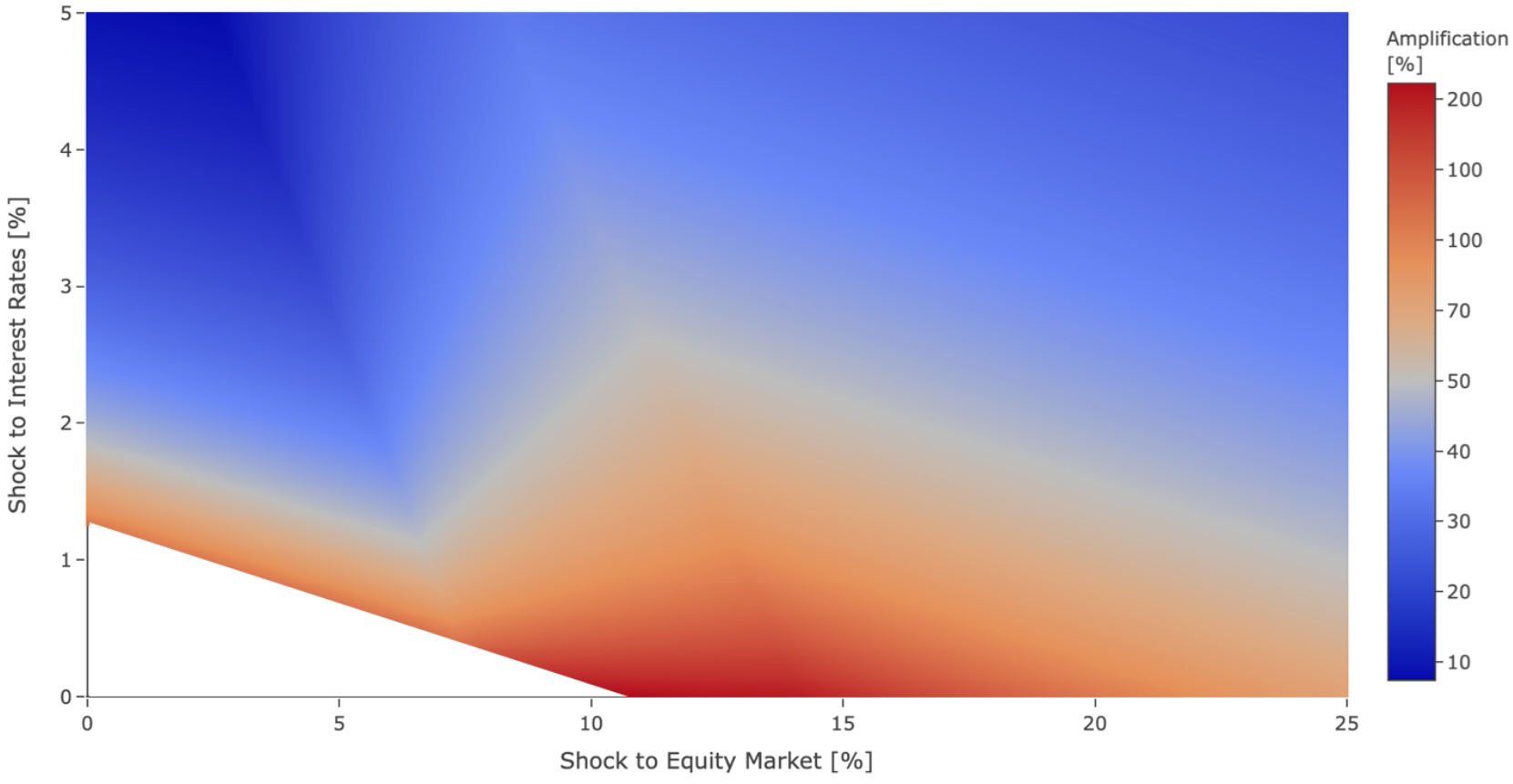


Figure 6: Equity loss amplification due to funding costs.

Summary

- Solvency affects liquidity and vice versa: they can not be modeled – or stressed – separately / independently.
- Coherent framework for joint modeling of solvency and liquidity risk:
  - Random shocks are applied to assets ('solvency shocks').
  - Solvency shocks affect liquidity through margin requirements, firm's ability to raise short-term funding and through credit risk sensitive outflows, leading to **endogenous liquidity shocks**.
  - More realistic stress test framework which establishes coherence between design of solvency and liquidity stress tests.
- **Solvency-liquidity diagram** gives a synthetic view of how balance sheet reacts to various types of market/credit shocks.
- Online tool: `http://liquidityatrisk.kotlicki.pl/`
- Paper: `Journal of Banking and Finance`, 118, Sept 2020

References

Allen, F. and D. Gale

1998. Optimal financial crises. *The Journal of Finance*, 53(4):1245–1284.

Cont, R.

2017. Central Clearing and Risk Transformation. *Financial Stability Review (Banque de France)*.

Diamond, D. W. and R. G. Rajan

2005. Liquidity Shortages and Banking Crises. *The Journal of Finance*, 60(2):615–647.

Du, W., S. Gadgil, M. B. Gordy, and C. Vega

2015. Counterparty risk and counterparty choice in the credit default swap market. *Federal Reserve Board, Washington DC*.

Liang, G., E. Lütkebohmert, and Y. Xiao

2013. A multiperiod bank run model for liquidity risk. *Review of Finance*, Pp. 1–40.

References (cont.)

Morris, S. and H. S. Shin

2016. Illiquidity component of credit risk. *International Economic Review*, 57(4):1135–1148.

Pierret, D.

2015. Systemic Risk and the Solvency-Liquidity Nexus of Banks. *International Journal of Central Banking*, 11(3):193–227.

Rochet, J.-C. and X. Vives

2004. Coordination failures and the lender of last resort: was Bagehot right after all? *Journal of the European Economic Association*, 2(6):1116–1147.

Schmitz, S. W., M. Sigmund, and L. Valderrama

2019. The interaction between bank solvency and funding costs: A crucial effect in stress tests. *Economic Notes*, 48:12130.