EUROPEAN CENTRAL BANK

EUROSYSTEM

Grzegorz Hałaj

An Agent-based model of liquidity and solvency interactions

13 September 2016, Cambridge

Motivation

- Liquidity risk is a systemic and a system-wide concept, turbulently driven by behaviors of market participants
- Complexity: connectivity of balance sheets and markets + liquidity coupled with solvency
- Severity: liquidity problems may unwind rapidly and turbulently
- Expected takeaway: a method to measure, monitor, counteract
- Approach taken: **agent-based modelling (ABM) of interacting agents responding to shocks**

Outline

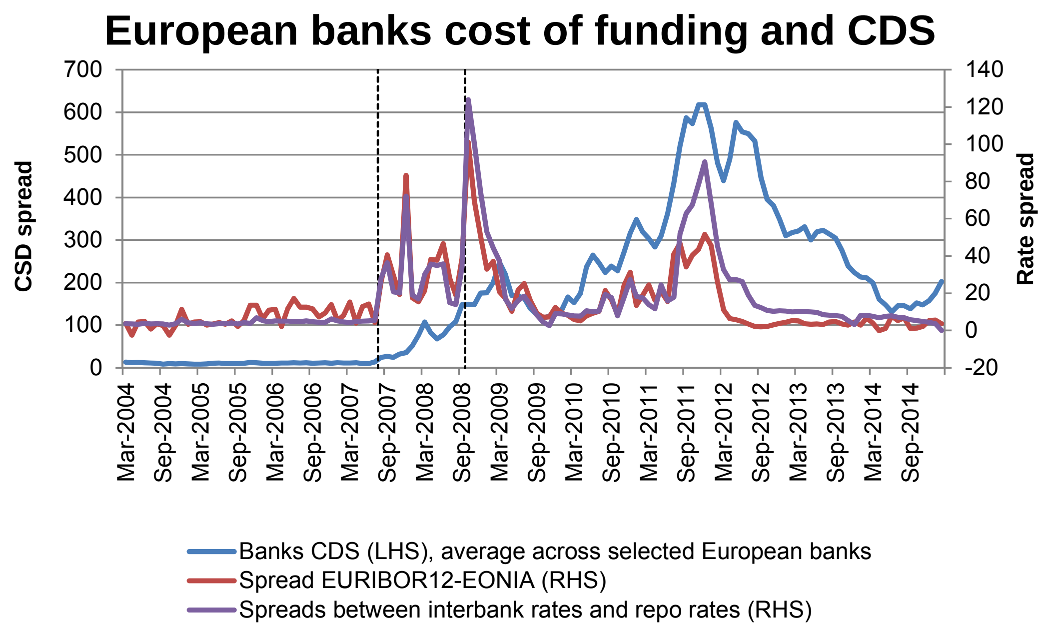
- Mechanisms of systemic liquidity risk
  - Recent example(s)
  - Some theory on the drivers

- Components of the Agent-based Model (ABM)
  - Role of ABM in finance
  - **Six steps of a (liquidity+solvency) default chain**
  - For policy assessment: randomly generated systems vs real data on interbank

- Simulations
  - Macroprudential policy analysis: Liquidity Coverage Ratio (LCR)-type limits + Capita Adequacy Ratio (CAR) limits
  - Conclusion: a lot of nonlinearity and cliff effects

Liquidity risk – how it become a global problem (1)

- 2007-2008 crisis partly related to liquidity and contagion – largest globally active, highly interconnected market players caught in an illiquidity trap (Drudi et al. (2011), ECB WP 1467)
- 2010 sovereign phase of the crisis also implying for banks issues with liquidity and contagion
- Second stage of the crisis: bank – sovereign nexus
- Before that: liquidity a “forgotten risk”...



Liquidity crisis – insight into mechanism

- Cifuentes, Ferrucci & Shin (2006)

[…When the market's demand for illiquid assets is less than perfectly elastic, sales by distressed institutions depress the market prices of such assets. Marking to market of the asset book can induce a further round of endogenously generated sales of assets, depressing prices further and inducing further sales…]

Small shock can cause big troubles!

- Brunnermeier & Pedersen (2008)

market liquidity:

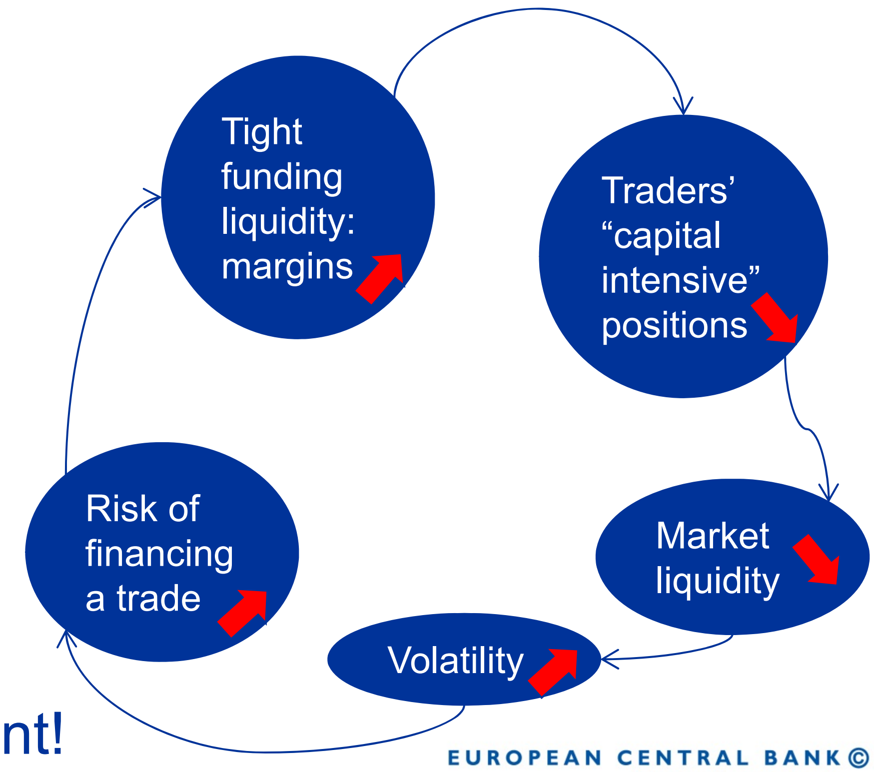
(i) can suddenly dry up

(ii) has commonality across securities,

(iii) is related to volatility,

(iv) is subject to "flight-to-quality,"

(v) co-moves with the market



Lots of non-linearity and reinforcement!

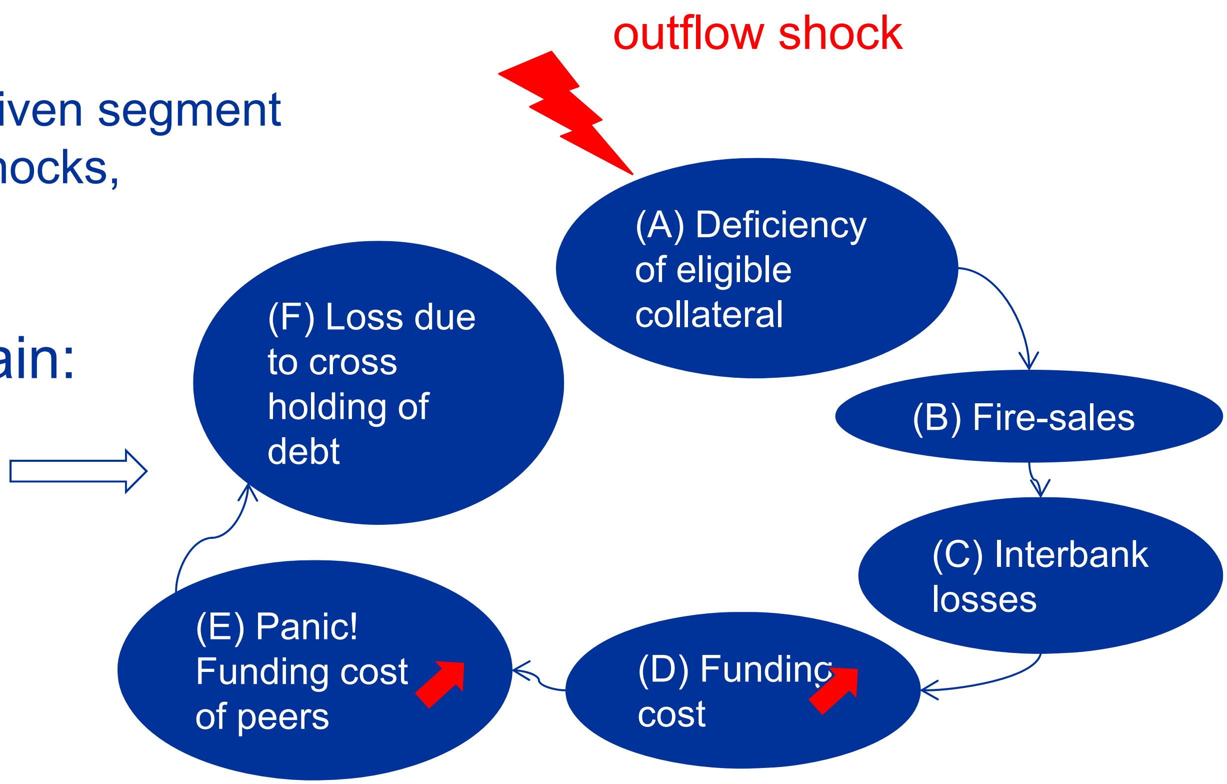
In financial context:

- Giansante et al. (2012): study of interactions between liquidity and solvency
  - Liquidity and solvency conditions for economic agents determine the bilateral flows based on the assessment of counterparty solvency and liquidity scoring index
- Klimek et al. (2015): deal with the efficiency of the bank resolution mechanisms
  - Confirming the intuition that a bail-in mechanism may perform better than other closer to the bail-out concept
- Bookstaber et al.: towards Agent-based modelling (ABM) approach
  - Interacting players: liquidity demanders, suppliers, market makers
  - Endogenising liquidity supply fluctuations (cyclical with periods of crises)

- **6-step approach**: a liquidity outflow triggers a chain of events in the banking system

- Shocking the system:
  - Outflow of deposits in a given segment (random / deterministic shocks, e.g. σ, 2σ,…)

- Shock transmission chain: chain of events is activated



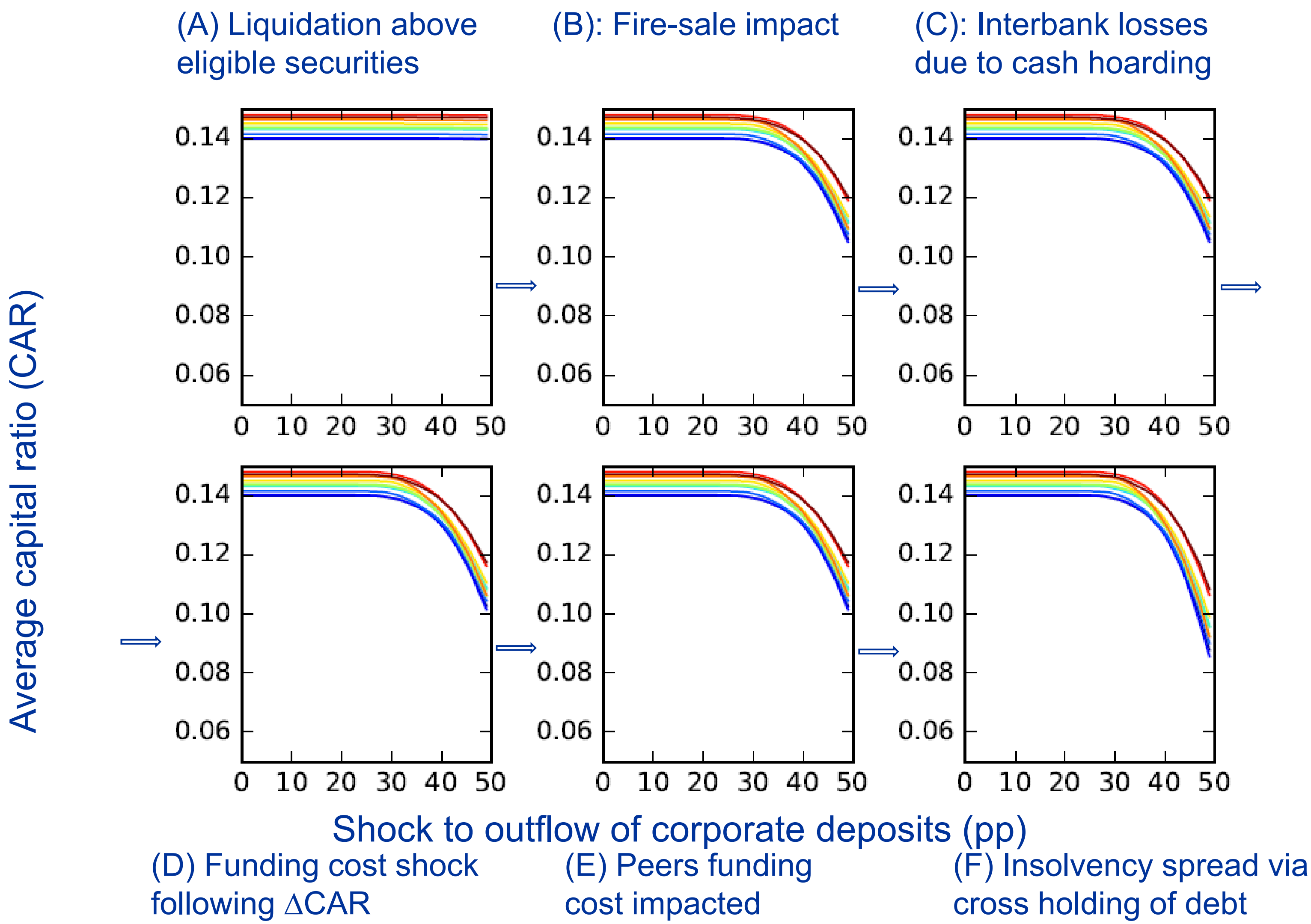
- Shock impact:
  - Illiquidity (default on liquidity if buffers unsufficient) – number of banks, liquidity ratio reduction,
  - Solvency: P&L+CAR impact

Sensitivity analysis of key parameters

- Creating banks (randomly, 100) composed of assets / liabilities from a given set, with given parameters, s.t. liquidity and solvency is admissible
- Accounting for the heterogeneity of sizes (Gamma distribution)
- Applying a liquidity shock and going through the sequence of events
- Repeating many times and aggregating the (CAR) results

(e.g. 1000 simulations of banks * 50 interbank markets * 100 scenarios of shocks → 5 million simulations)

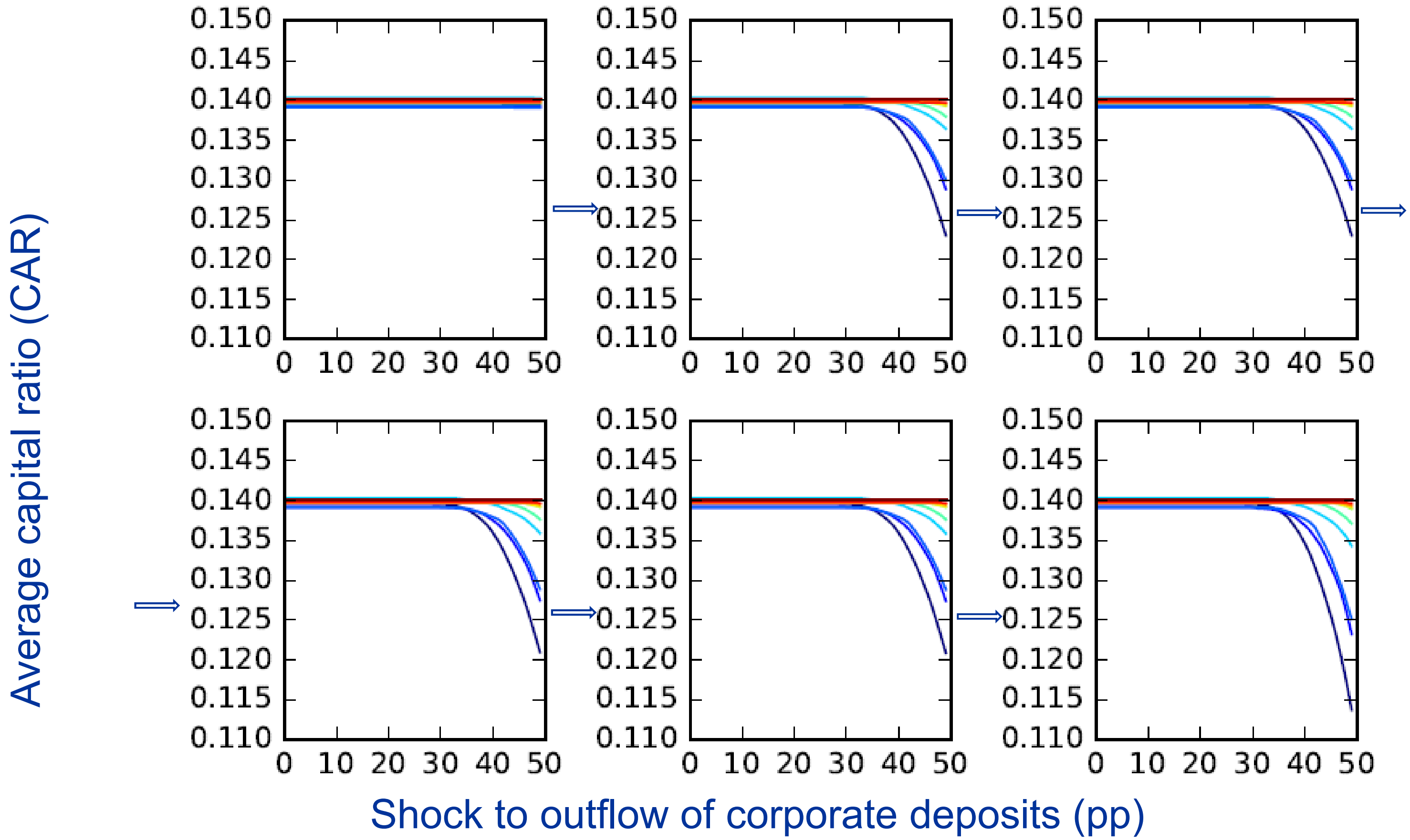
Targeting solvency – CAR threshold to mitigate contagion



Note: Sequence of simulations: shock to corporate deposits and covered bonds in country A; x-axis – outflow (%); y-axis – average CAR; lines correspond to CAR threshold in (8%; 9%)

Targeting liquidity – LCR to mitigate contagion

(A) Liquidation above eligible securities | (B): Fire-sale impact | (C): Interbank losses due to cash hoarding



(D) Funding cost shock following ΔCAR | (E) Peers funding cost impacted | (F) Insolvency spread via cross holding of debt

Note: Sequence of simulations: shock to corporate deposits and covered bonds in country A; x-axis – outflow (%); y-axis – average CAR; lines correspond to LCR in (1; 1.1)

Real system: structure of the BS input data

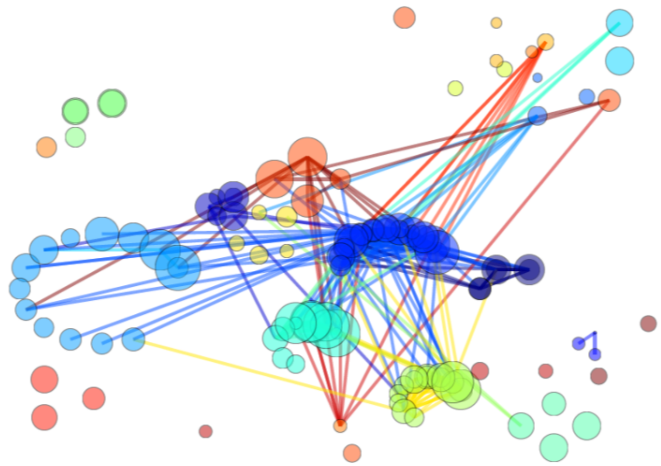
	Balance sheet side	Volume				Interest rate	Risk weight	Liquidity risk weight
		25th prct	median	mean	75th prct	mean (wght)	mean (wght)	mean (wght)
EQUITY	E	1595	3131	8318	1595	0	0	0
CB_CENT_GVMT	A	369	1575	8642	369	0.03	6	25
INST	A	725	3987	25311	725	0.02	23	2
CORP	A	1844	9118	23651	1844	0.06	106	4
RETAIL_SEC_RE	A	266	7751	27324	266	0.06	48	6
RETAIL_QUAL_REVOLV	A	0	4	602	0	0.14	59	1
RETAIL_OTH	A	216	2249	10195	216	0.08	56	2
SECURITISATION	A	0	0	750	0	0.02	26	0
OTH_NON_CREDIT	A	0	0	1248	0	0.02	31	0
HTM__SOV	A	0	108	2489	0	0.05	7	0
HTM__OTH	A	0	422	4746	0	0.04	7	0
AFS__SOV	A	299	2963	7182	299	0.04	8	0
AFS__OTH	A	33	755	3978	33	0.04	8	0
FVTPL__SOV	A	0	17	2002	0	0.03	8	0
FVTPL_OTH	A	0	36	3132	0	0.03	7	0
UNSEC_IB_A	A	47	1095	6793	47	0.02	39	0
SEC_IB_A	A	0	270	5652	0	0.01	34	0
NON_BANK_CORP_DEP_SIGHT	L	273	2453	9023	273	0.01	*na*	6
NON_BANK_CORP_DEP_TERM	L	180	1148	7026	180	0.02	*na*	7
RETAIL_DEP__SIGHT	L	208	7455	26728	208	0.01	*na*	3
RETAIL_DEP___TERM	L	163	4551	15184	163	0.03	*na*	4
GVMT_DEP__SIGHT	L	0	83	722	0	0	*na*	2
GVMT_DEP___TERM	L	0	138	1214	0	0.02	*na*	3
UNSEC_IB_L	L	467	2065	9518	467	0.02	*na*	10
SEC_IB_L	L	0	2227	7273	0	0.01	*na*	8
SNR_UNSEC_DEBT	L	34	2778	11877	34	0.04	*na*	10
COV_BONDS	L	0	1698	8640	0	0.04	*na*	5
OTH_OWN_DEBT	L	0	503	4661	0	0.05	*na*	10
CERT_DEPOSIT	L	0	0	2523	0	0.01	*na*	10
COMM_PAPER	L	0	0	607	0	0.01	*na*	10
STRUCT_PRODUCTS	L	0	0	1888	0	0.01	*na*	25
ABS	L	0	0	1390	0	0.02	*na*	50
ELA	L	0	0	293	0	0.01	*na*	0
OTH_CB_L	L	0	810	4913	0	0	*na*	0
CB_DEPOSIT	L	63	425	2509	63	0	*na*	0

20K datapoints for ≈120 banks to analyse

LST TD tools – network contagion models

Network models based on financial institutions' (in particular banks') exposures help to

- **Assess the contagion risk**: scope and magnitude of transmission
- **Identify systemic institutions**: these nodes that cause a cascade of problems
- **Assess effectiveness of various policy measures aimed at mitigating these risks**: LE limits, RWs and capital buffers on the systemically important institutions



<= Own debt issued (simulated) network based on 2014 EBA ST data

Unsecured interbank lending (simulated) network based on 2014 EBA ST data =>

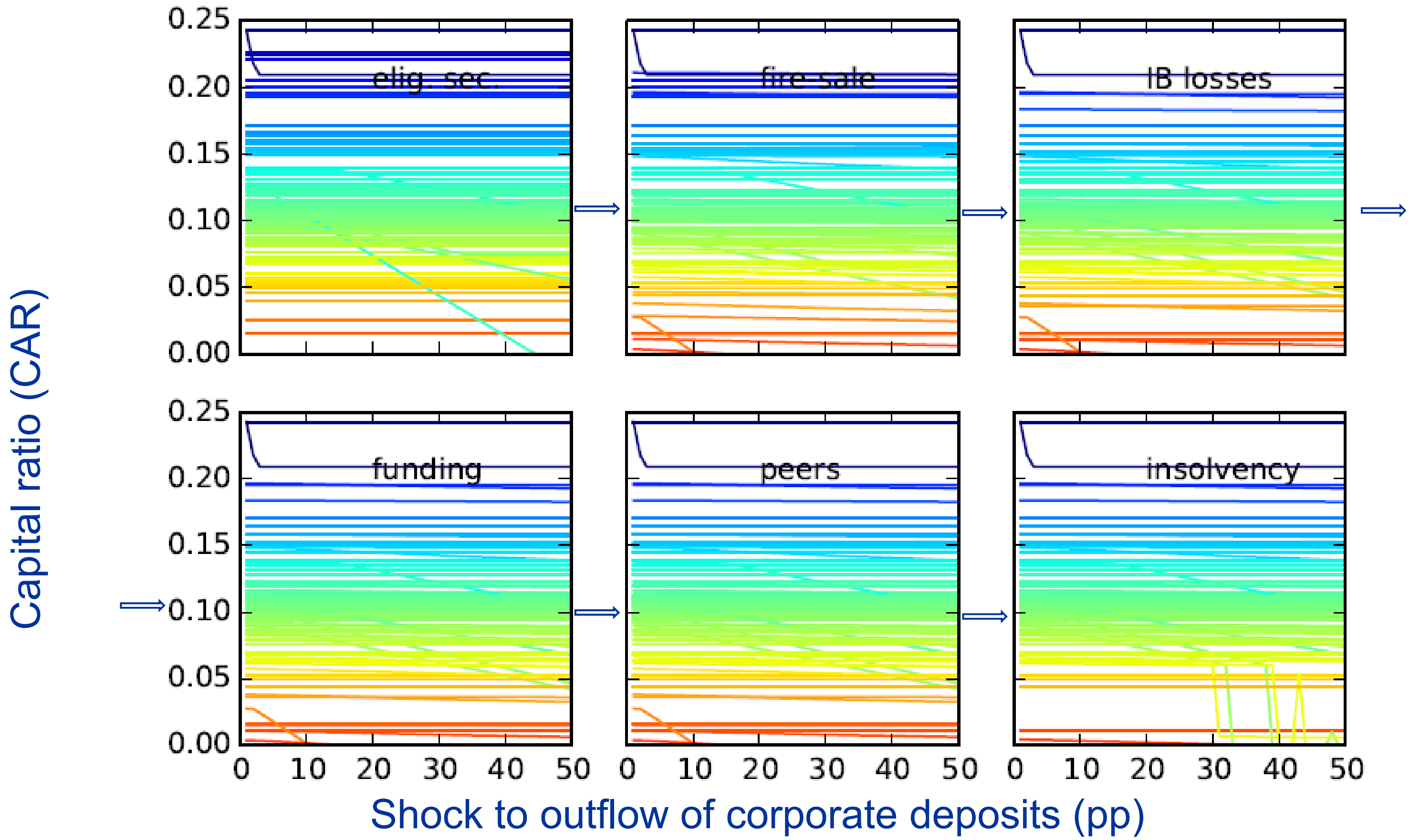
Circle indicate a banks (size ~ log(total assets)); link = exposure

Sequence of simulations: outflow of corp. depo and covered bonds in country A

(A) Liquidation above eligible securities

(B): Fire-sale impact

(C): Interbank losses due to cash hoarding



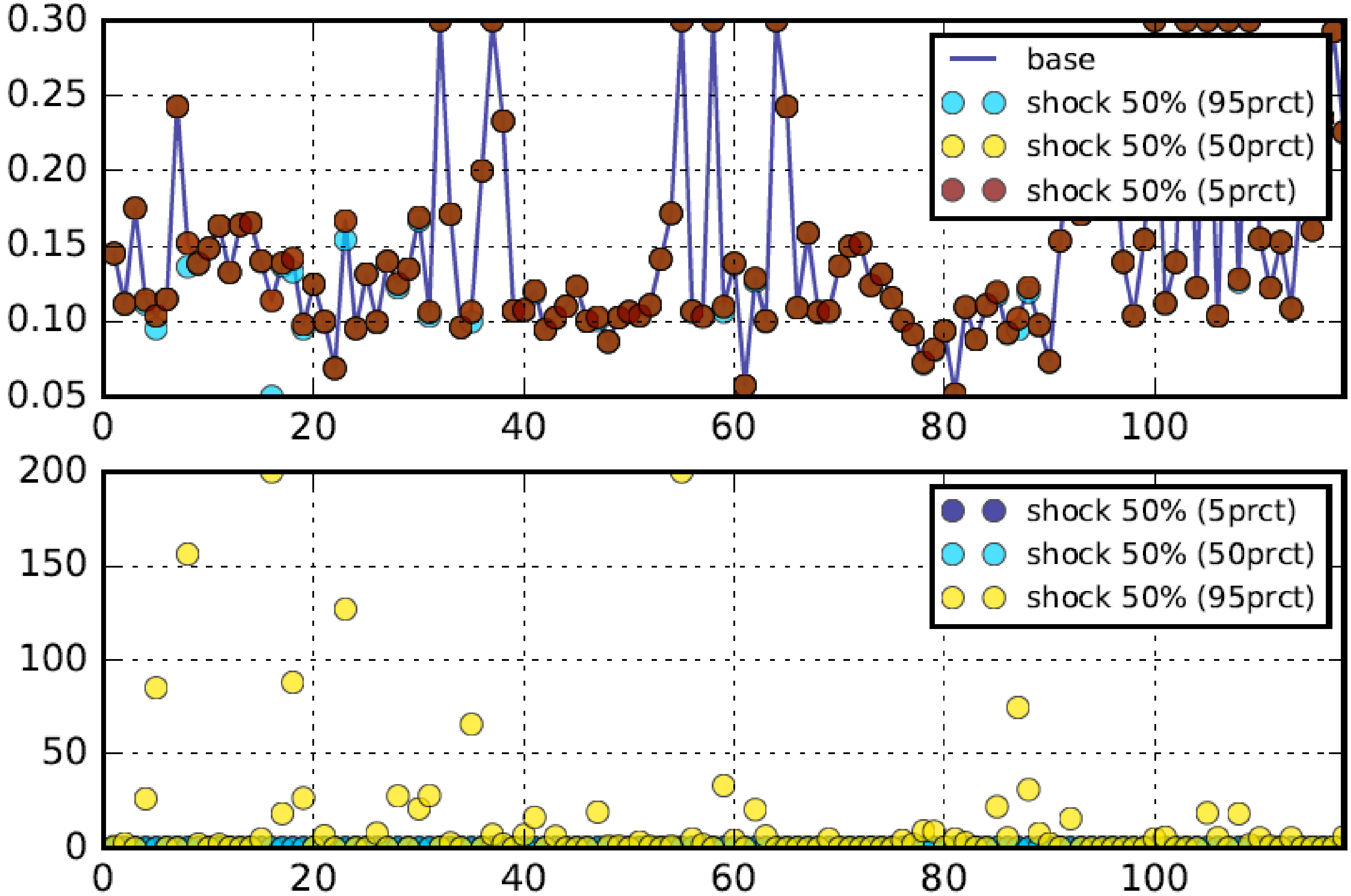
(D) Funding cost shock following ΔCAR

(E) Peers funding cost impacted

(F) Insolvency spread via cross holding of debt

Note: x-axis – outflow (%); y-axis – CAR

CAR impact on the 2.5% shock, percentiles across randomly selected banks affected by initial liquidity shock

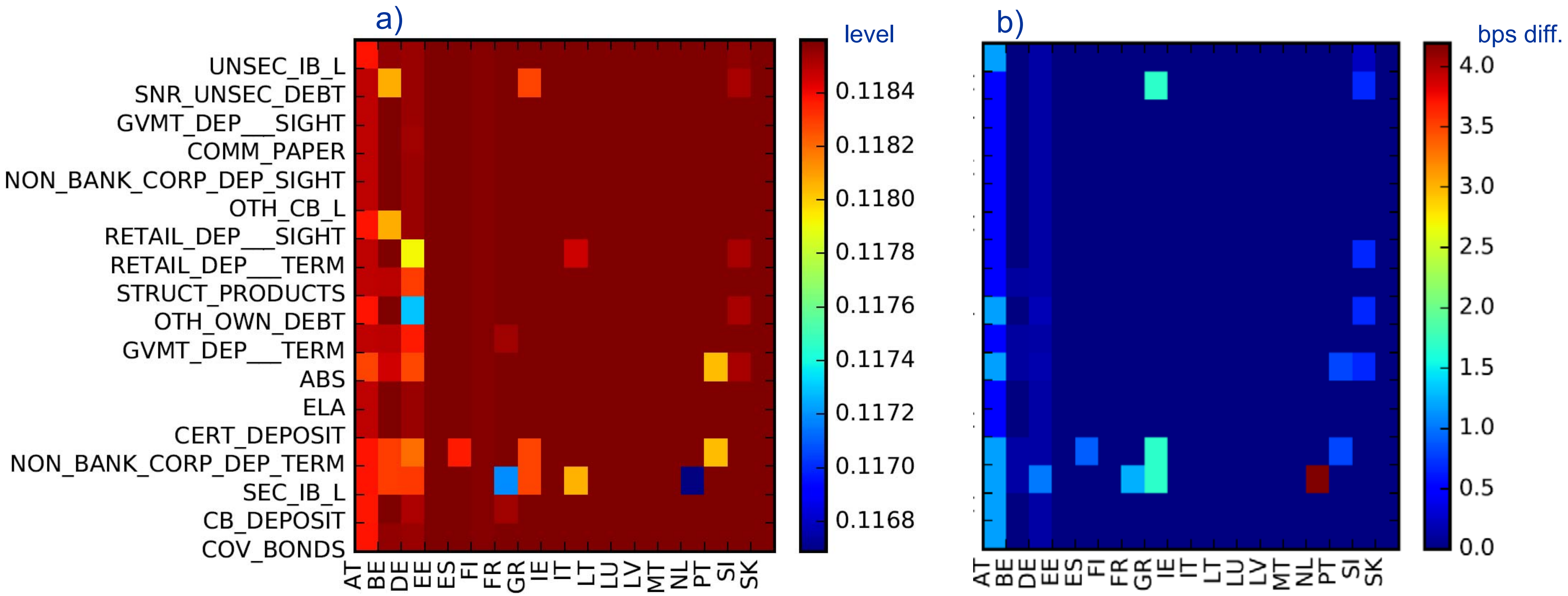


Note: top pane – CAR; bottom pane – deviation from initial car (bps)

Heatmap of vulnerabilities

Design:

- Set funding outflow parameter = 20%
- Choose funding category *c* and bank *b* and run the 6-step simulation for a 20% outflow for category *c* in bank *i*
- Aggregate the results per country XX (panel a) reports results for all pairs (*i*,*c*))
  → **total systemic risk effects**
- Compute the average difference between the average CAR before and after 6-steps for all banks outside country XX (panel b) reports results for all pairs (*i*,*c*))
  → **cross-border effects**



Conclusions

- Still work in progress (further parameterization work, robustness checks)
- Country instead of currency perspective: data available
- Correlated shocks on investment (asset) and funding (liability)
- Multi-period extension: a fully ABM implementation -> liquidity shock -> balance sheet reaction -> liquidity shock -> balance sheet reaction...
- Optimising banks: endogenising the behaviours

ANNEX

Model details

Model – input parameters (I)

- Balance sheet of bank b is composed of some N generic classes of assets $(a_1^b, \ldots, a_N^b)$, M liabilities $(l_1^b, \ldots, l_M^b)$ and capital e^b and the balance sheet sum identity holds ($\bar{N} :=\{1, \ldots, N\}$, $\bar{M} :=\{1, \ldots, M\}$):

$$\sum_n a_n^b = \sum_m l_m^b + e^b$$

- Outflow parameter $f_m^{O,b}$, $m \in \bar{M}$: fraction of volume that flows out (or is not rolled over)
- Haircut h_n: a haircut on the book value of the securities in case of liquidation

Model – input parameters (II)

- Eligibility $\mathcal{E} \subset \bar{N}$: a set of asset classes that are eligible in CB operations; noneligible: $\mathcal{NE} := \bar{N}/\mathcal{E}$
- Fire sales elasticity α_n: implying revaluation of assets by a factor of $1 - \exp(-\sum_{n \in \mathcal{NE}} \alpha_n \Delta a_n^b)$
- Solvency conditions: risk weights applied to the exposures $\Rightarrow$ RWA $\Rightarrow$ (divided by capital) capital ratio (CR)
- Interbank market: of direct lending (matrix I, $I_{k_1 k_2}$: k_2 lends to k_1) and cross-holdings of debt securities issued by banks (matrix B)
- Maturity profile of funding μ_m: deterioration of CR $\Rightarrow$ maturing wholesale funding repriced at a higher cost
- MtM-recognised assets impacted by the revaluation: $\mathcal{M} \subset \bar{N}$

Model – liquidity shock

A liquidity shock is practically an outflow of deposits, which is a bank-specific vector s^b, s.t. $s^b_m := f^{O,b}_m l^b_m \in [0, l^b_m]$.
Assets are characterised by liquidity haircuts $h_n \in [0, 1]$.
If

$$\sum_{n \in \mathcal{E}} (1 - h_n) a^b_n > \sum_{m \in \bar{M}} s^b_n$$

then deficiency observed: $D^b := \sum_{m \in \bar{M}} s^b_m - \sum_{n \in \mathcal{E}} (1 - h_n) a^b_n$ – needs to be supplemented by 'fire sales'

Model – impact of fire sales

MtM revaluation of securities

$$e^{fs*,b} := e^b - \sum_{n \in \mathcal{M}} a_n^b \exp(-\sum_{(k,x) \in \mathcal{L}^k} \mathbb{I}_{\{k=n\}} \alpha_k x)$$

repricing of a given asset class by the aggregate volume of liquidated assets on the market depending on the depth of the market (α)

Spill over to the interbank market

Debtors need to search for other sources of funding which is a costly process (cost $\equiv$ fraction of volume).

$$e^{fs,b} := e^{fs*,b} - \sum_{k \in \mathcal{DL}} c^l l_{bk}$$

Model – banks $\mathcal{ES}$ with significantly affected capital ratio

$$\mathcal{T}_d :=[\tau_{d-1}, \tau_d) \qquad \mathcal{ES} := \{b | \frac{e^b}{\Omega_b} - \frac{e^{fs,b}}{\Omega_b} > \Delta^\tau\}$$

Direct effects

$$e^{Inc,b} = e^{fs,b} + \sum_n r_n a_n^b - \sum_m c_m l_m^b$$

Accounting for the relationship between funding cost and solvency leads to:

$$e^{IncS,b} = e^{Inc,b} - \sum_m \left(\sum_d \mathbb{I}_{\{\frac{e^b - e^{fs,b}}{\sum_n \omega_n a_n^{fs,b}} \in \mathcal{T}_d\}} \Delta c_m^d l_m^b \mu_m^b \right)$$

Indirect effects

The peers of $\mathcal{ES}$ are affected as well. A peer: any bank with a similar structure of the balance sheet (cosine of balance sheet vectors is $> 1 - \epsilon$)

Model – solvency defaults

- If for any reason the capital ratio falls below a regulatory threshold $\tau^b \longrightarrow$ the bank defaults.
- We assume that it means default of payment of the interbank liabilities (with a given LGD, set uniformly for the interbank market) and defaults on the bonds issues that are held across the market.
- These two layers of interconnectedness transfer the shocks of the solvency defaults throughout the interbank market