# Systemic risk in financial multilayer networks - and how to manage it

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with Sebastian Poledna

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S Poledna, S Thurner, Elimination of systemic risk in financial networks by means of a systemic risk transaction tax, Quantitative Finance (2016)

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S. Poledna, O. Bochmann, S. Thurner Basel III fails to control systemic risk and can cause pro-cyclical side effects (2015) (arXiv:1602.03505)

M.V. Leduc, S. Thurner, Incentivizing Resilience in Financial Networks (2016) (arXiv:1606.03595)

funded in part by

# Part I: What is systemic risk?

# The three types of risk

- **economic risk:** investment in business idea does not pay off
- **credit-default risk:** you don't get back what you have lent
- **systemic risk:** system stops functioning due to local defaults and subsequent (global) cascading

# Economic risk

risk that business idea does not fly – fails – investments are lost

- who takes this risk? The financial system!
- this is a service of financial system to economy
- this service should not introduce new risks: as long as it does

$\rightarrow$ financial system is ill designed

- **management:** hard to get rid of this type of risk

# Credit-default risk

if I lend something – there is risk that I will not get it back

estimate for credit-worthiness: assets–liabilities

- **management:** capital requirements for lending

$\rightarrow$ Basle-type regulation

# Systemic risk

- risk that significant fraction of financial network defaults
- systemic risk is **not** the same as credit-default risk
- banks care about credit-default risk
- banks have no means to manage systemic risk

$\longrightarrow$ role of regulator: **manage systemic risk**
$\longrightarrow$ incentivise banks to think of SR

# Two origins of systemic risk

- **synchronisation of behaviour**: fire sales, margin calls, herding including various amplification effects. May involve networks
- **networks of contracts**: this is manageable

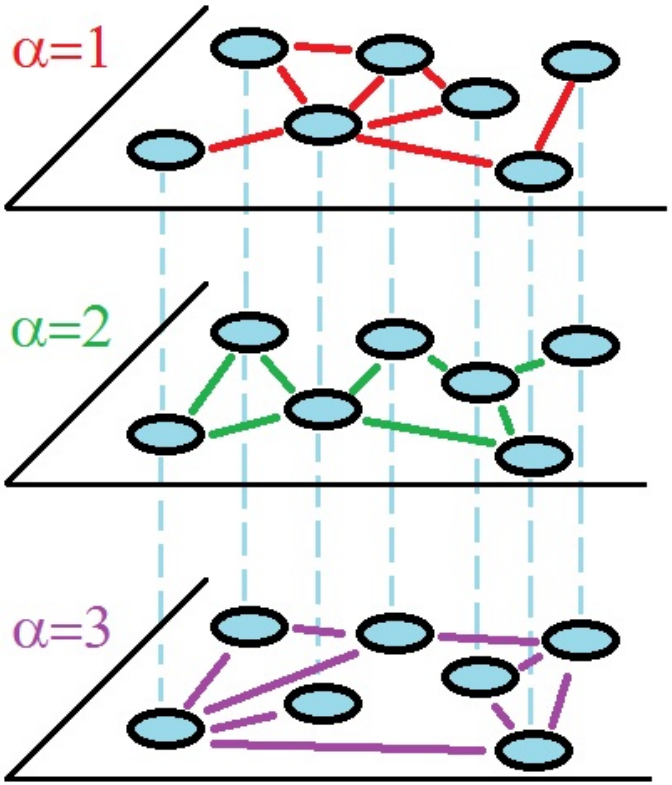
# How does systemic risk spread?

SR spreads **by borrowing from others!**

if you borrow **from** systemically risky nodes
$\rightarrow$ you increase your systemic risk

note: credit-default risk spreads by lending to

# Systemic risk is a multiplex network




layer 1: lending–borrowing loans

layer 2: derivatives

layer 3: collateral

layer 4: securities

layer 5: cross-holdings

layer 6: overlapping pfolios

layer 7: liquidity: over-night loans

layer 8: FX transactions

# Part II: Quantification of SR

# Systemic risk – quantification

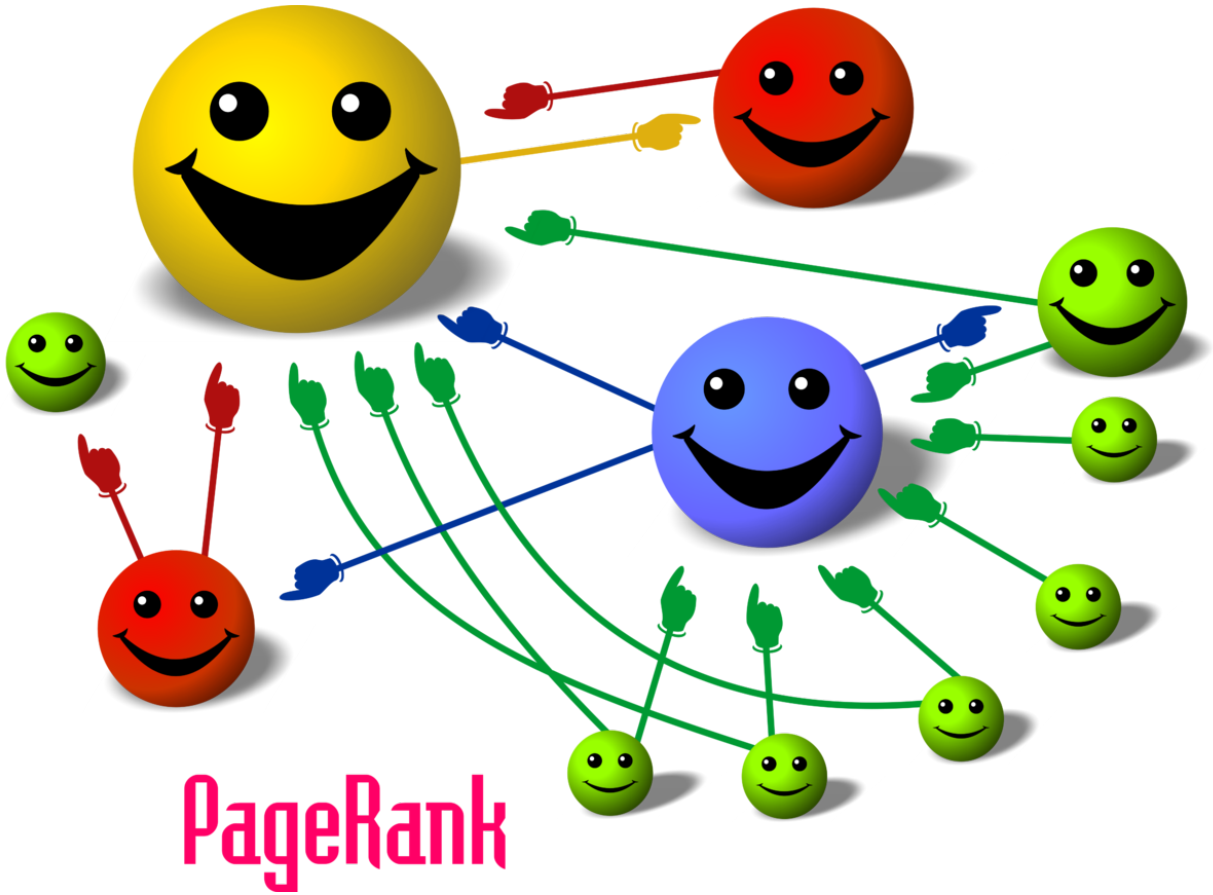
**Wanted:** systemic risk-value for every financial institution

Google has similar problem: value for importance of web-pages

$\rightarrow$ page is important if many important pages point to it

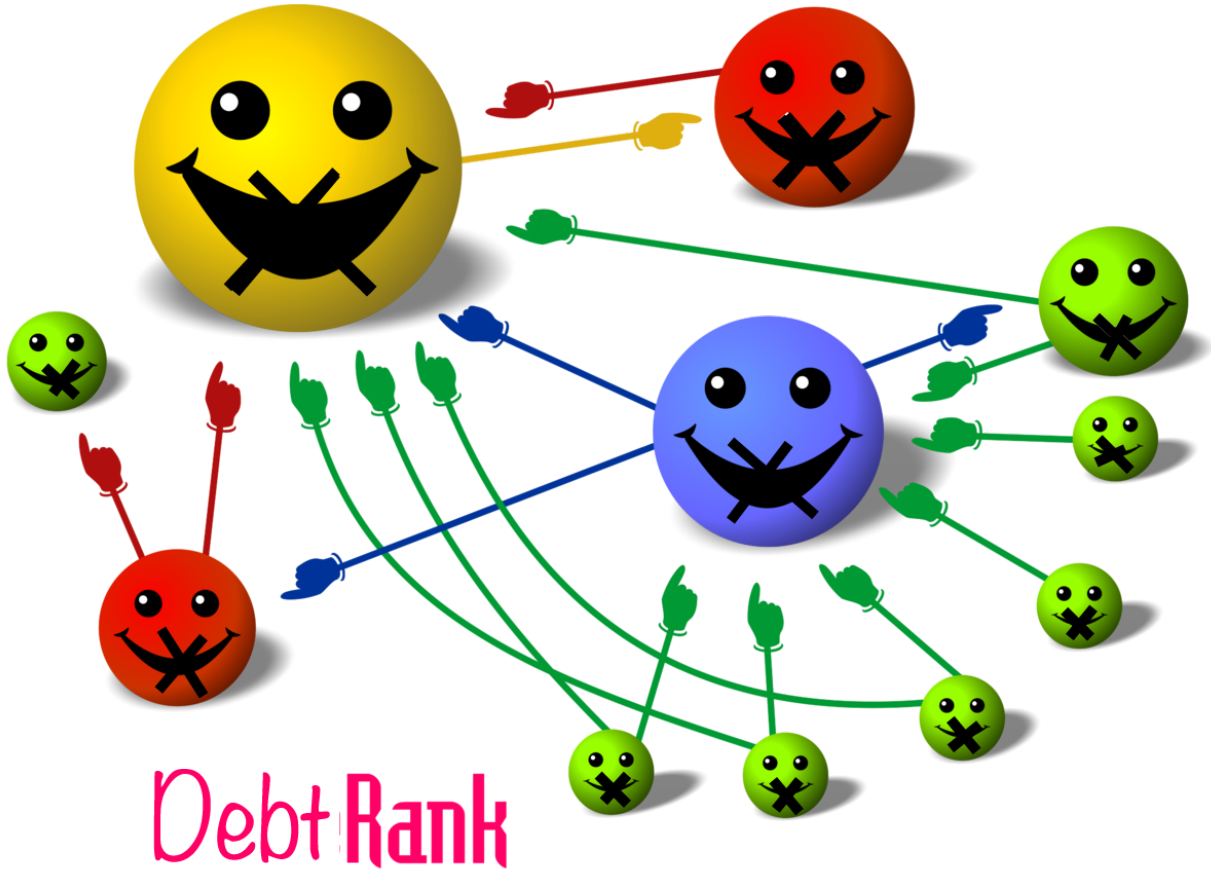
$\rightarrow$ number for importance $\rightarrow$ PageRank

page is **important** if many **important** pages point to it




source Wikipedia cc-license

institution system. risky if system. risky institutions lend to it



# Systemic risk factor – DebtRank $R$

... is a "different Google" – adapted to context of systemic risk (S. Battiston et al. 2012)

superior to: eigenvector centrality, page-rank, Katz rank ... Why?

- quantifies systemic relevance of node in financial network with economically meaningful number
- **economic value** in network that is affected by node's default
- takes capitalization/leverage of banks into account
- takes cycles into account: no multiple defaults

# DebtRank

- recursive method
- corrects Katz rank for loops in the exposure network
- if $i$ defaults and can not repay loans, $j$ loses $L_{ij}$. If $j$ has not enough capital to cover that loss $\rightarrow$ $j$ defaults
- impact of bank $i$ on neighbors $I_i = \sum_j W_{ij} v_j$

with $W_{ij} = \min\left[1, \frac{L_{ij}}{C_j}\right]$, ouststanding loans $L_i = \sum_j L_{ji}$, and $v_i = L_i / \sum_j L_j$

- impact on nodes at distance two and higher $\rightarrow$ recursive

$$I_i = \sum_j W_{ij} v_j + \beta \sum_j W_{ij} I_j,$$

If the network $W_{ij}$ contains cycles the impact can exceed one
$\rightarrow$ DebtRank (S. Battiston et al. (2012))

- nodes have two state variables, $h_i(t) \in [0,1]$ and $s_i(t) \in \{Undistress, Distress, Inactive\}$
- Dynamics: $h_i(t) = \min\left[1, h_i(t-1) + \sum_{j|s_j(t-1)=D} W_{ji} h_j(t-1)\right]$

$$s_i(t) = \begin{cases} D & \text{if } h_i(t) > 0; s_i(t-1) \neq I \\ I & \text{if } s_i(t-1) = D \\ s_i(t-1) & \text{otherwise} \end{cases}$$

- DebtRank of set $S_f$ (set of nodes in distress), is

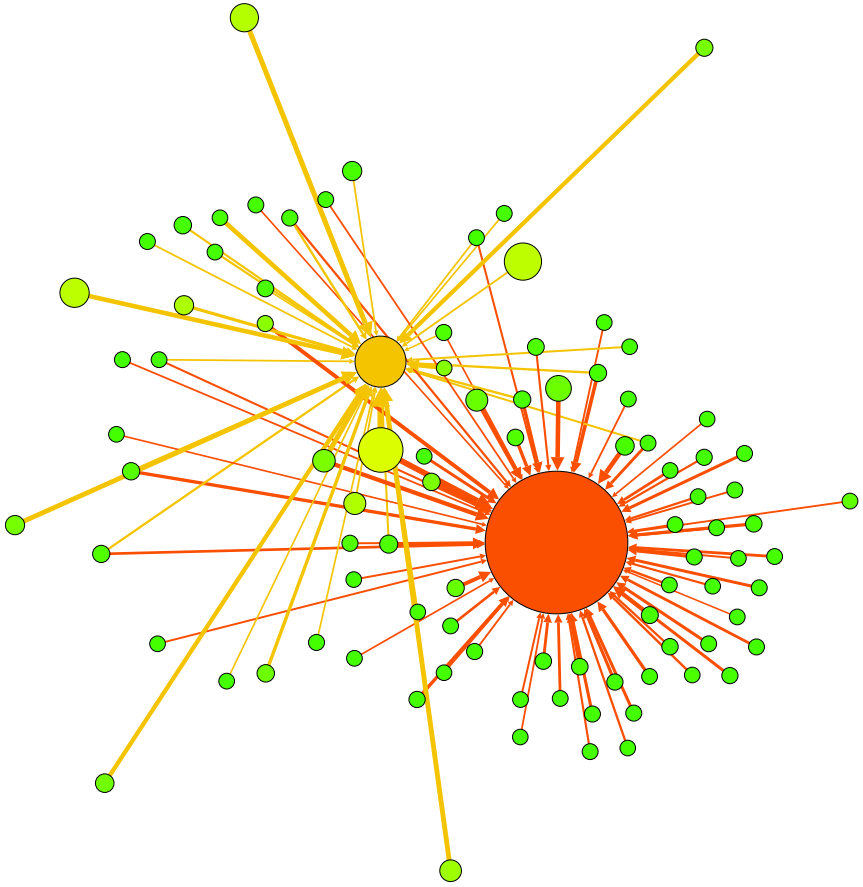
$$R_S = \sum_j h_j(t) v_j - \sum_j h_j(1) v_j$$

Measures distress in the system, excluding initial distress. If $S_f$ is a single node, DebtRank measures its systemic impact on the network.

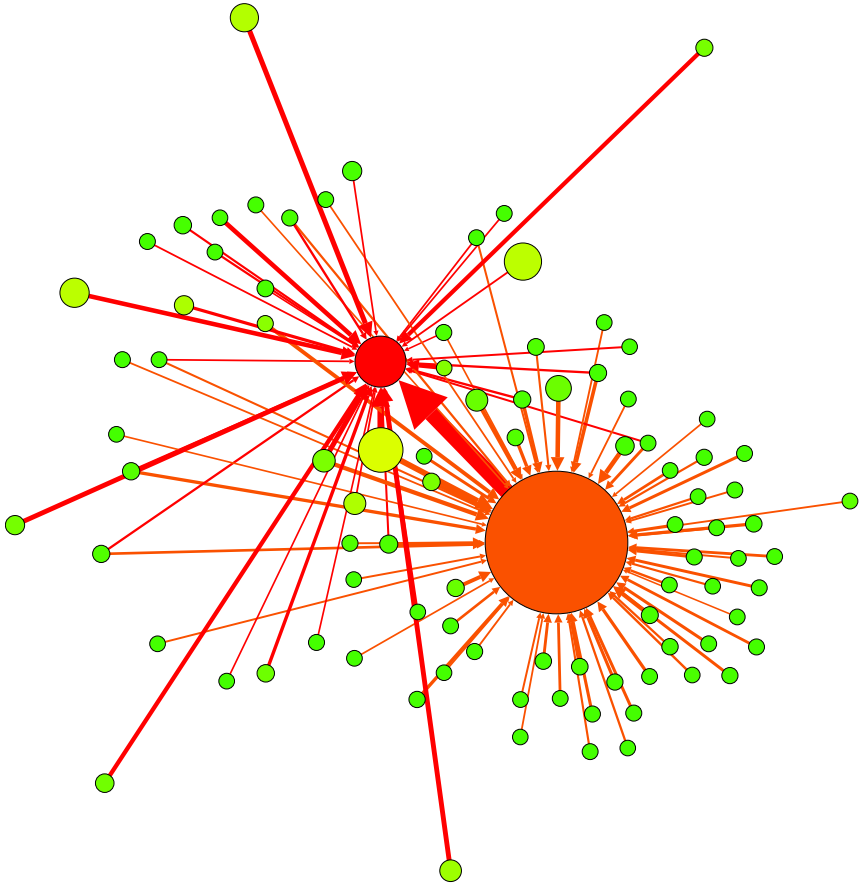
- DebtRank of $S_f$ containing only the single node $i$ is

$$R_i = \sum_j h_j(t) v_j - h_i(1) v_i$$

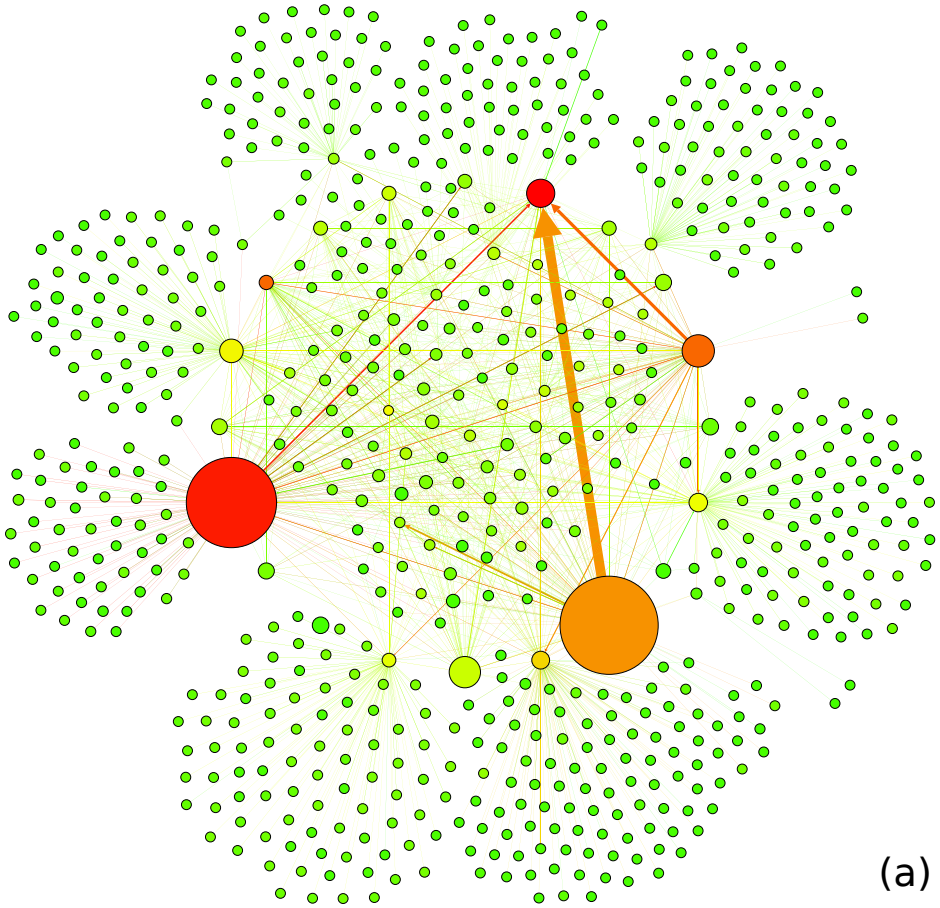
# Systemic risk spreads by borrowing



# Systemic risk spreads by borrowing



# DebtRank Austria Sept 2009

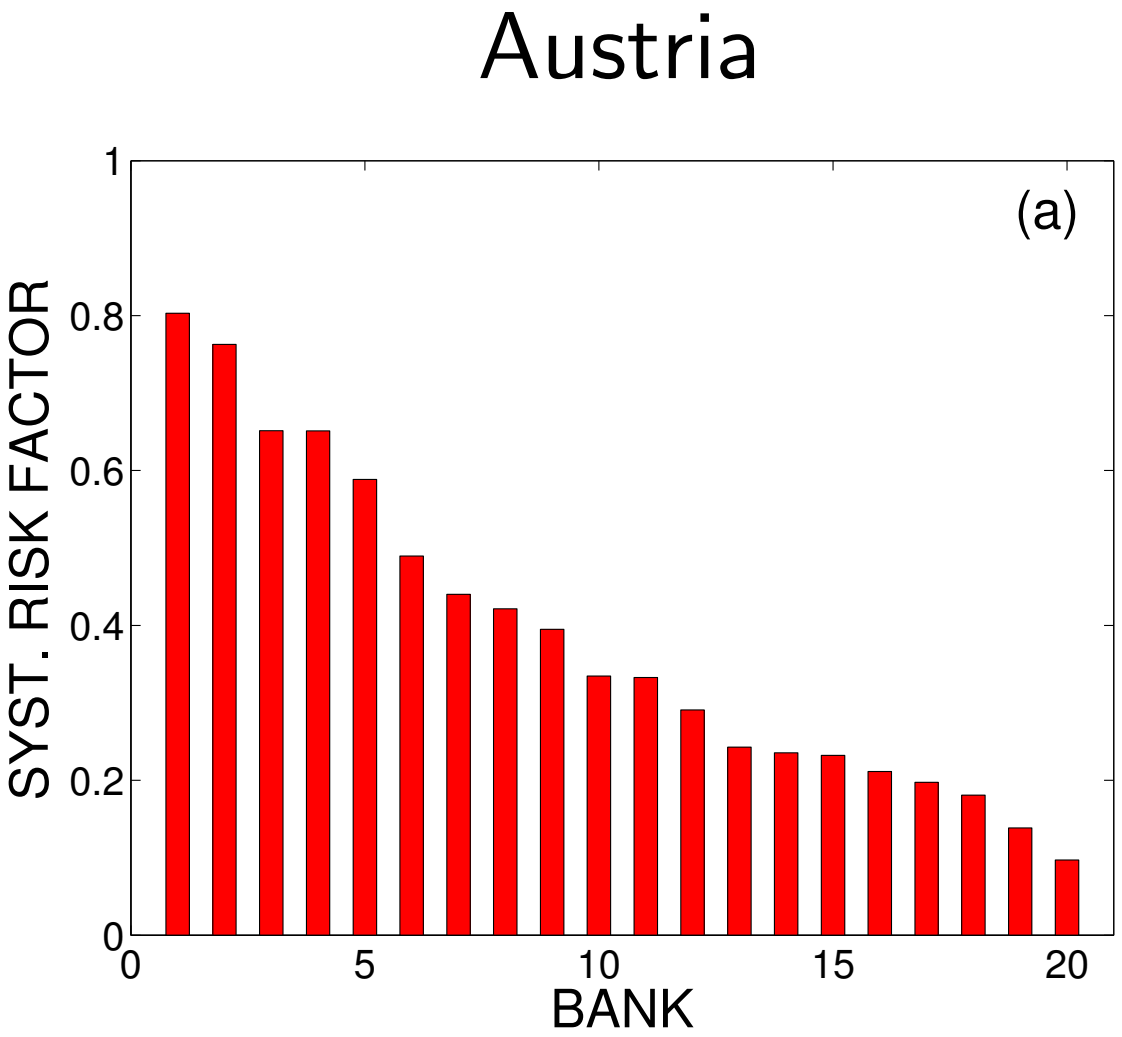


(a)

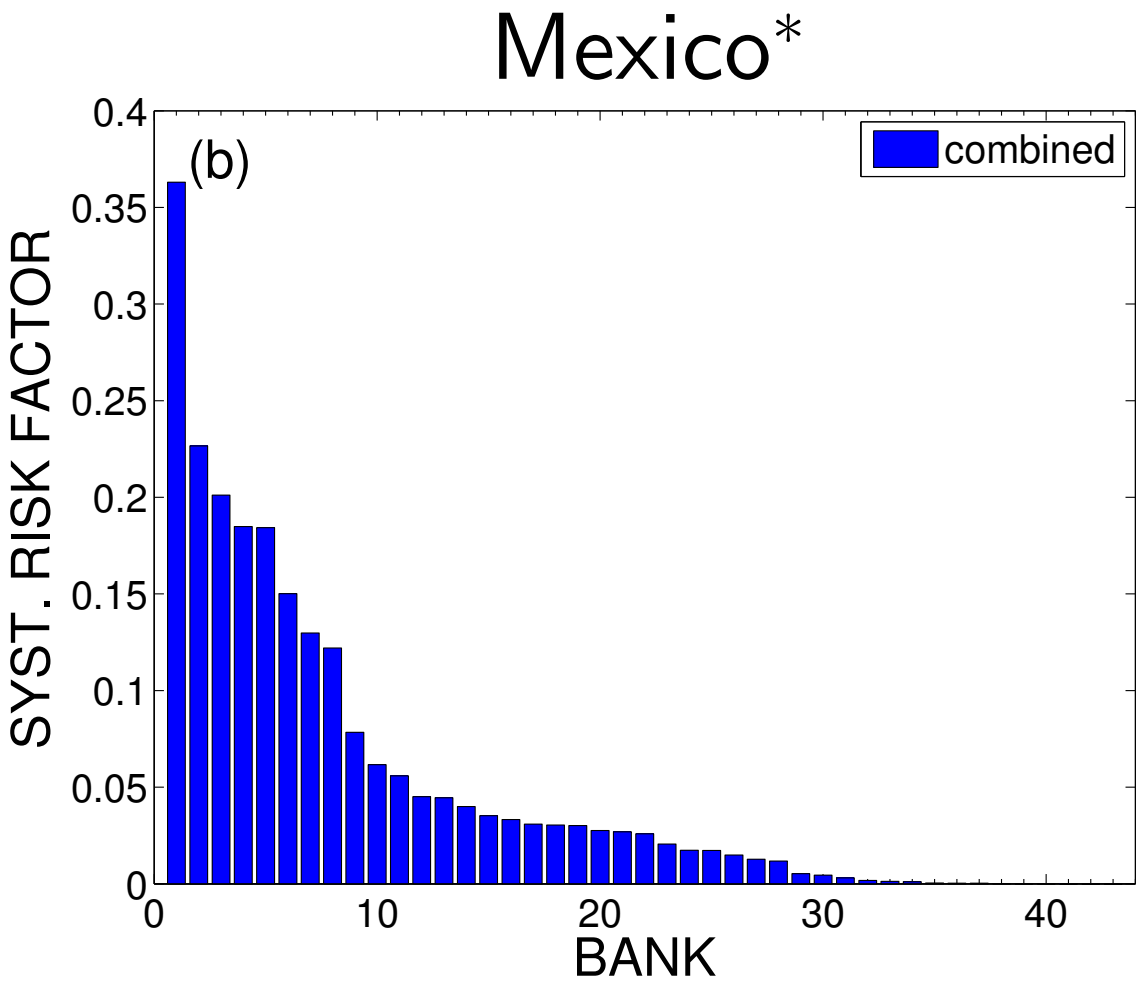
note: size is not proportional to systemic risk

note: core-periphery structure

# Systemic risk profile

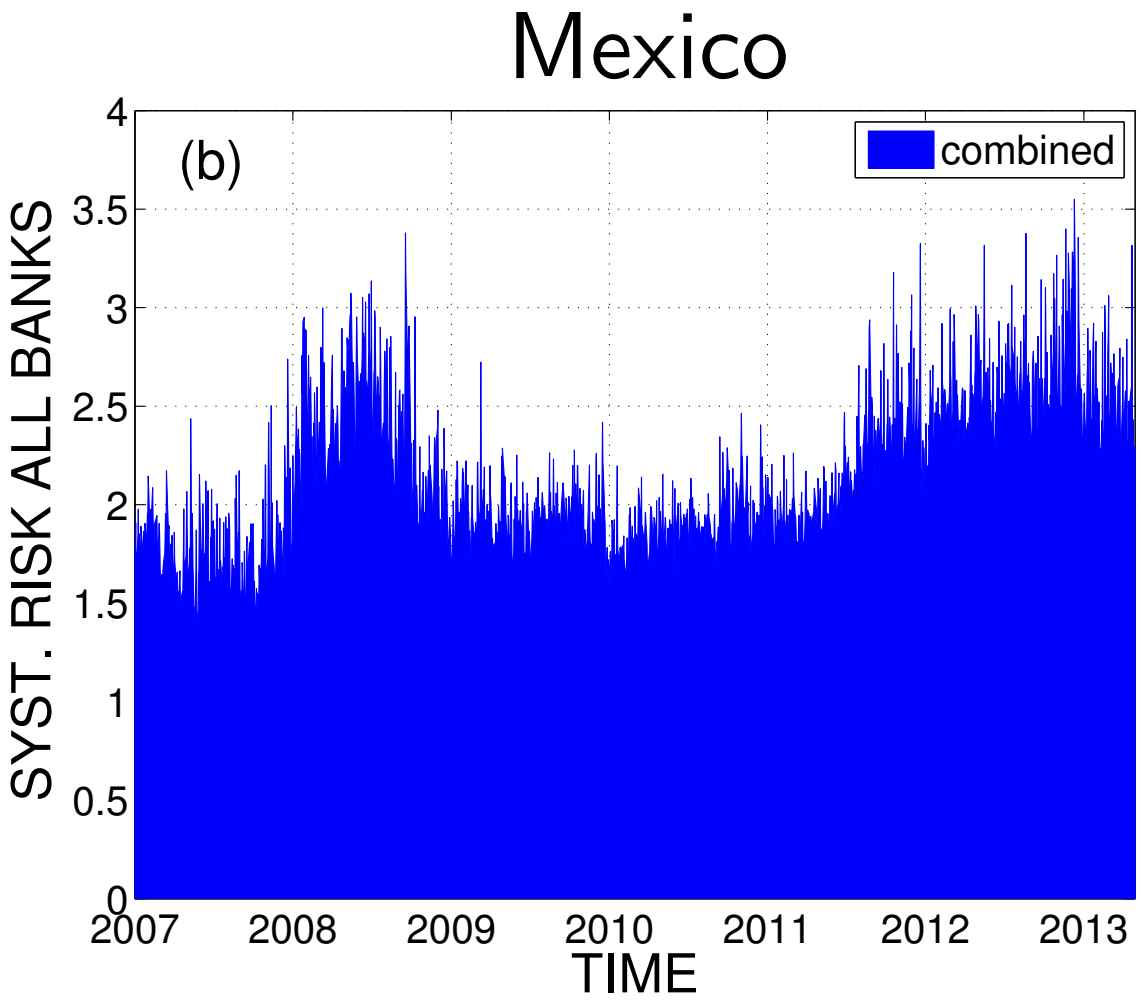


# Systemic risk profile




*with Serafin Martinez-Jaramillo and his team at Banco de Mexico, 2014

# Daily assessment of systemic risk is possible



# Systemic risk $\rightarrow$ expected systemic loss

**Expected loss** for bank $i$ (stress testing)

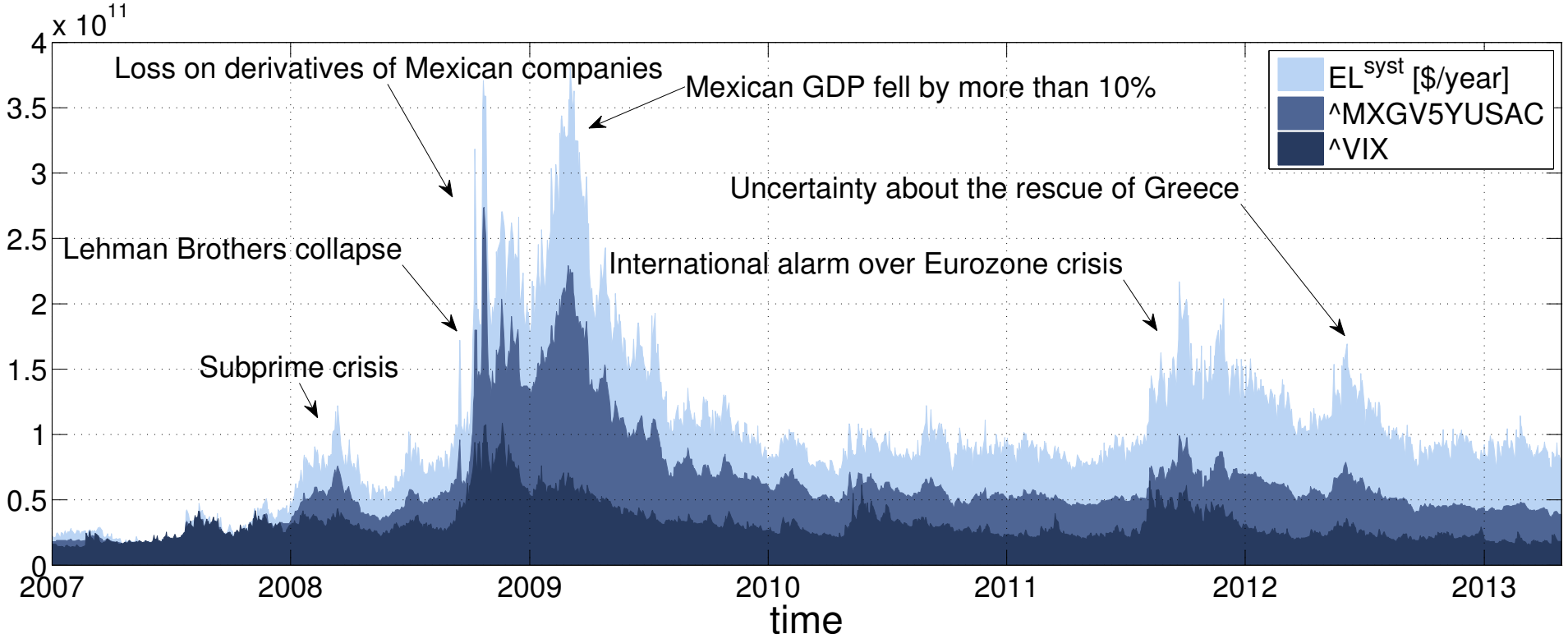
Expected loss(i)=$\sum_j p_{default}$(j).Loss-given-default(j).Exposure(i,j)

**Expected systemic loss** = $\sum_i p_{default}$(i) . DebtRank(i)

units: Euro / Year

$$
\begin{aligned}
\mathrm{EL}^{\mathrm{syst}} &= V \sum_{S \in \mathcal{P}(B)} \prod_{i \in S} p_i \prod_{j \in B \setminus S} (1 - p_j)\,(R_S) \\
&\approx V \sum_{S \in \mathcal{P}(B)} \prod_{i \in S} p_i \prod_{j \in B \setminus S} (1 - p_j) \left( \sum_{i \in S} R_i \right) \\
&= V \sum_{i=1}^{b} \underbrace{\left( \sum_{J \in \mathcal{P}(B \setminus \{i\})} \prod_{j \in J} p_j \prod_{k \in B \setminus (J \cup \{i\})} (1 - p_k) \right)}_{=1} p_i \, R_i \\
&= V \sum_{i=1}^{b} p_i \, R_i
\end{aligned}
$$

# Expected systemic loss index for Mexico*




*with Serafin Martinez-Jaramillo and team at Banco de Mexico, 2014

# Expected systemic loss index

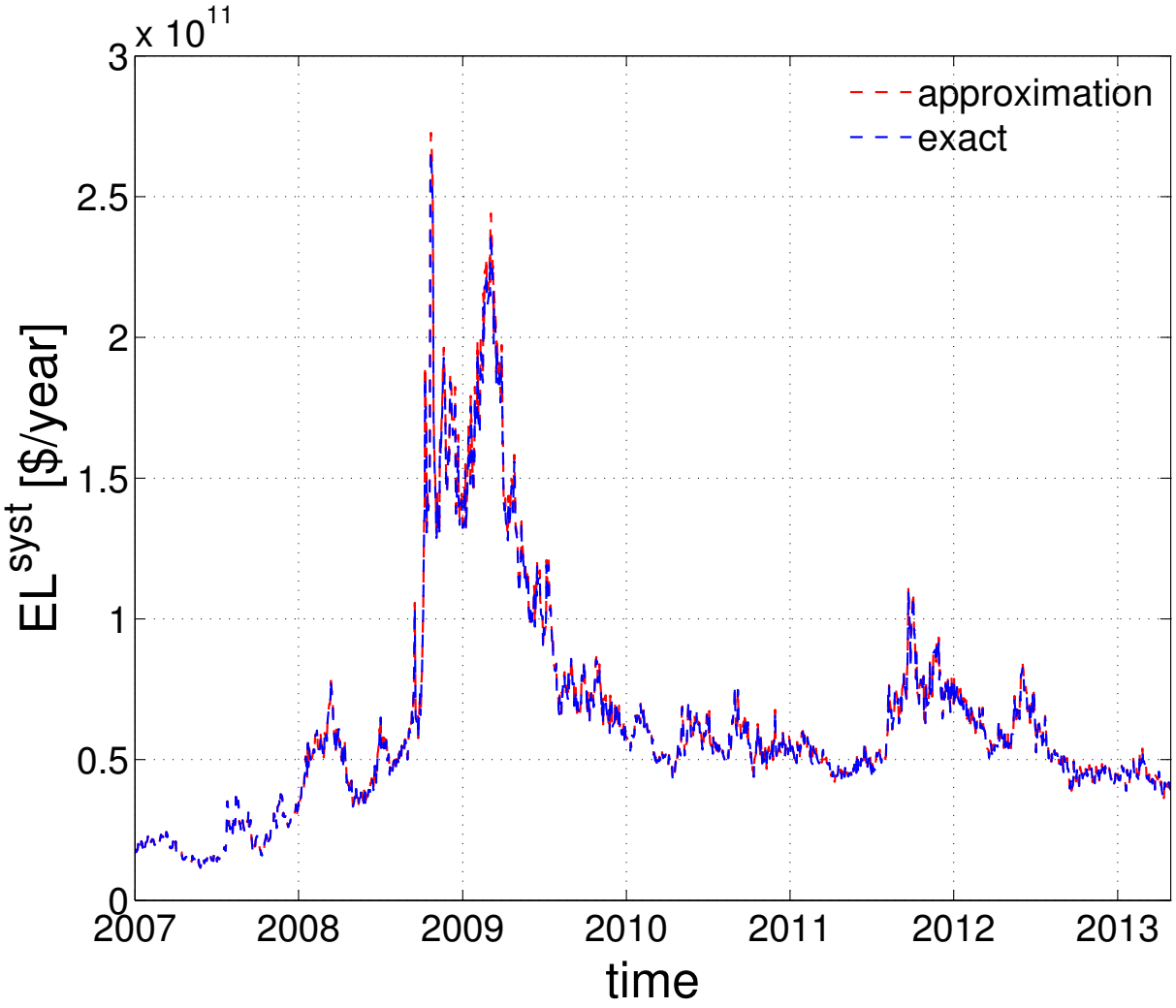
- expected losses per year within country in case of severe default and NO bailout

$\rightarrow$ rational decision on bailouts

- allows to compare countries
- allows to compare situation of country over time

$\rightarrow$ are policy measures taking action in Spain? in Greece?

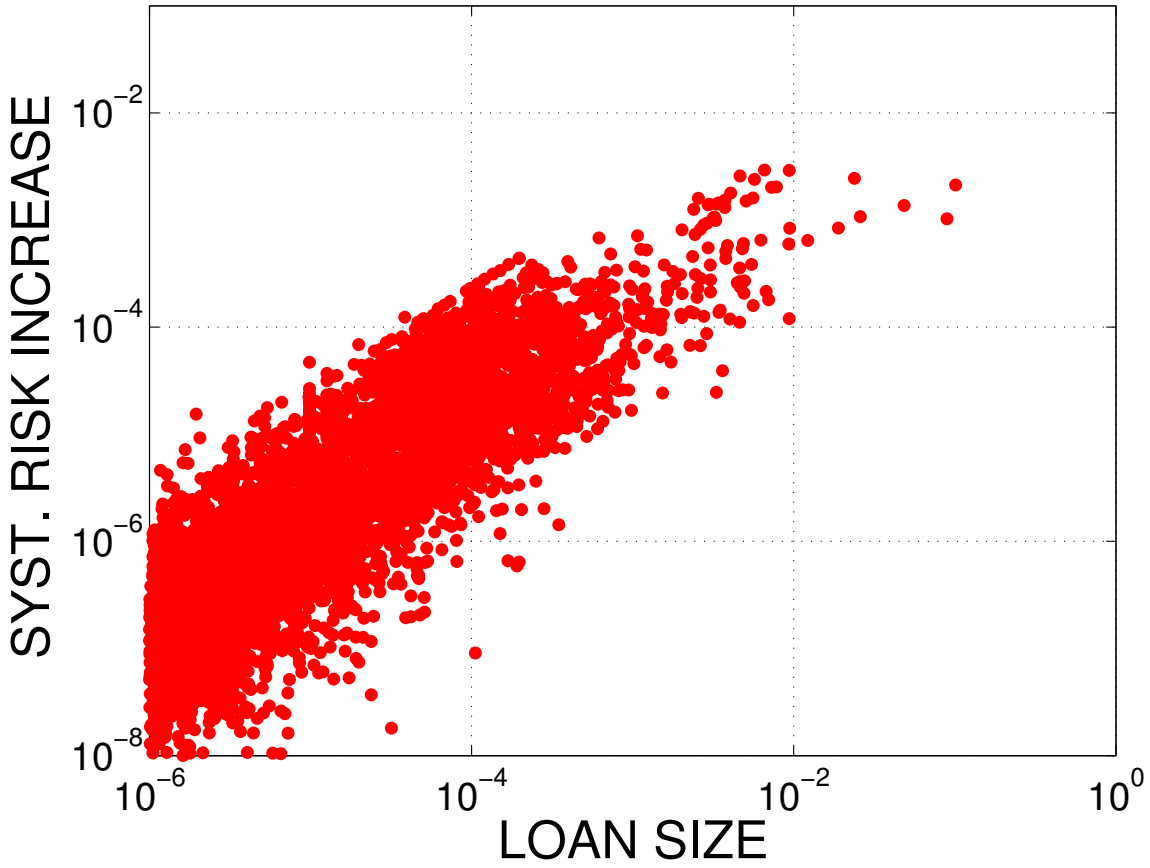
# Expected systemic loss index: error



# Observation

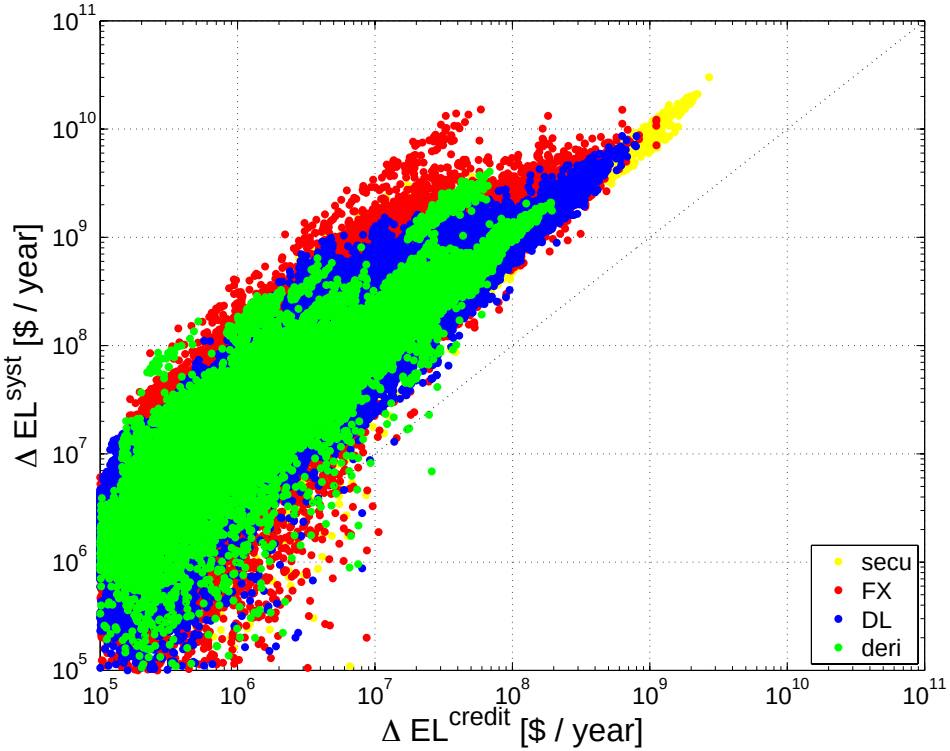
Systemic risk of a node changes with every transaction

# Austria all interbank loans




note orders of magnitude !

# Mexican data




$\Delta EL^{\text{syst}} > \Delta EL^{\text{credit}} \rightarrow$ defaults **do not only affect lenders** but involves third parties

# systemic risk is an externality

# Management of systemic risk

- Systemic risk is a network property to large extent
- Manage systemic risk: **re-structure financial networks** such that cascading failure becomes unlikely, ideally impossible

systemic risk management

=

re-structure networks

# Systemic risk elimination

- systemic risk spreads by borrowing from risky agents
- how risky is a transaction? $\rightarrow$ increase of expected syst. loss
- ergo: restrict borrowing from those with high DebtRank

$\rightarrow$ **tax those transactions** that increase systemic risk

# Systemic risk tax

- tax transactions according to their systemic risk contribution

$\rightarrow$ agents look for deals with agents with low systemic risk
$\rightarrow$ liability networks re-arrange $\rightarrow$ eliminate cascading

**No one should pay the tax – tax serves as incentive to re-structure networks**

- size of tax = expected systemic loss of transaction (government is neutral)

- if system is risk free: no tax

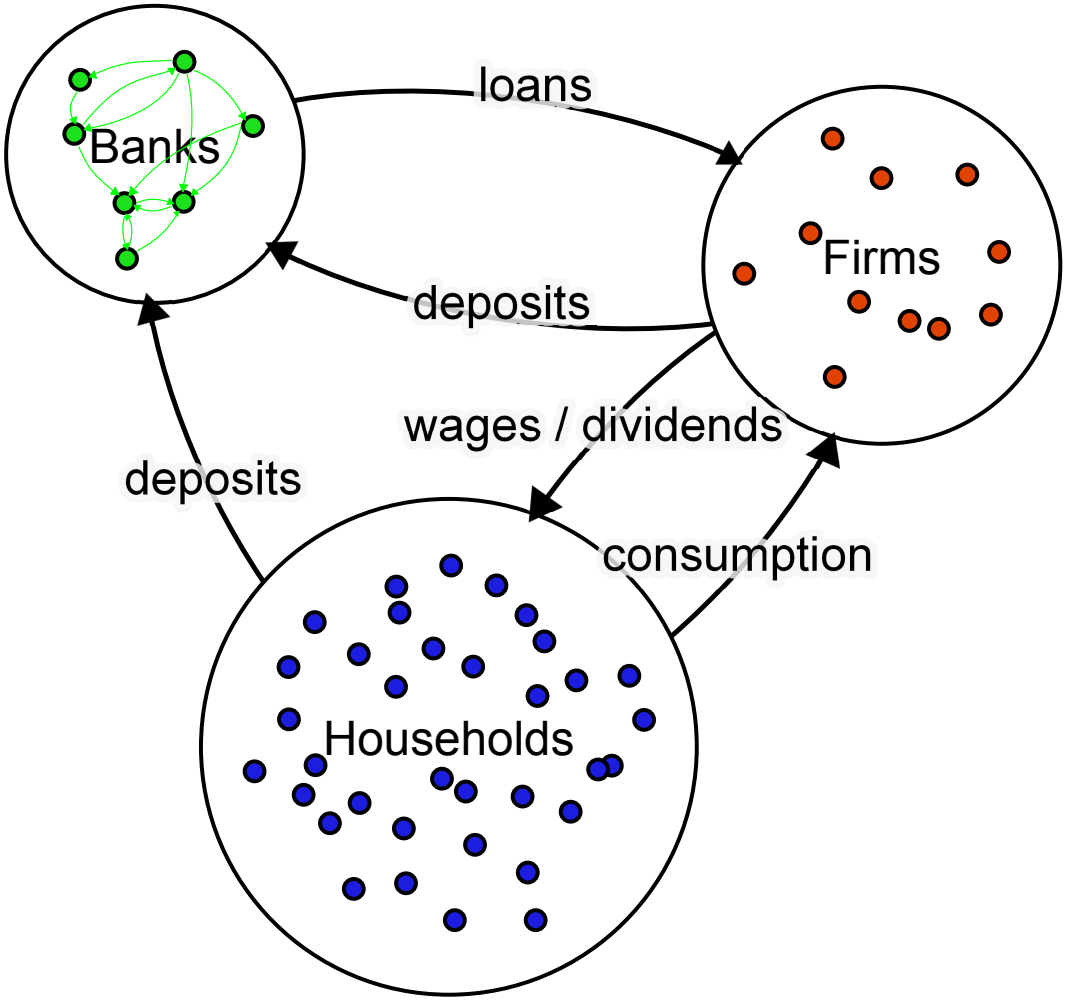
- credit volume should not be affected by tax

# Self-stabilisation of systemic risk tax

- those who can not lend become systemically safer
- those who are safe can lend and become unsafer
- $\rightarrow$ new equilibrium where systemic risk is distributed evenly across the network (cascading minimal)

$\rightarrow$ self-organized critical

# To test efficacy of tax: Crisis Macro-Financial Simulator (schematic)



# The agents

- **firms:** ask bank for loans: random size, maturity $\tau$, $r^{\mathrm{f-loan}}$

$\rightarrow$ firms sell products to households: realise profit/loss

$\rightarrow$ if surplus $\rightarrow$ deposit it bank accounts, for $r^{\mathrm{f-deposit}}$

$\rightarrow$ firms are bankrupt if insolvent, or capital is below threshold

$\rightarrow$ if firm is bankrupt, bank writes off outstanding loans

- **banks** try to provide firm-loans. If they do not have enough

$\rightarrow$ approach other banks for interbank loan at interest rate $r^{\mathrm{ib}}$

$\rightarrow$ bankrupt if insolvent or equity capital below zero

$\rightarrow$ bankruptcy may trigger other bank defaults

- **households** single aggregated agent: receives cash from firms (through firm-loans) and re-distributes it randomly in banks (household deposits, $r^{\mathrm{h}}$), and among other firms (consumption)

# For comparison: implement Tobin-like tax

- tax all transactions regardless of their risk contribution
- 0.2% of transaction ($\sim$ 5% of interest rate)

# Simulations: measure losses, cascades and efficiency

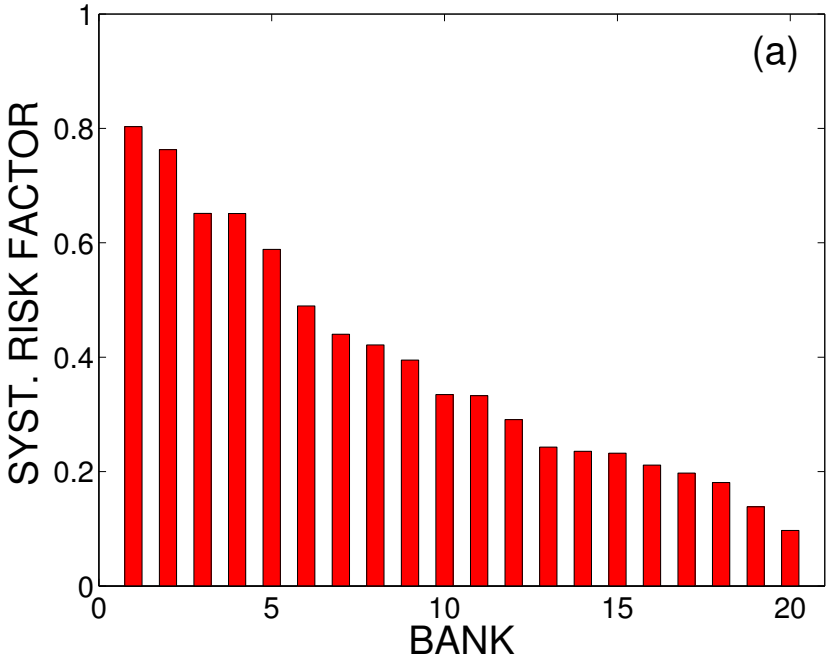
- **total losses to banks** resulting from a default/cascade
- **cascade size**: number of defaulting banks in systemic event
- **credit volume**: total credit volume in interbank market

# Comparison of three schemes

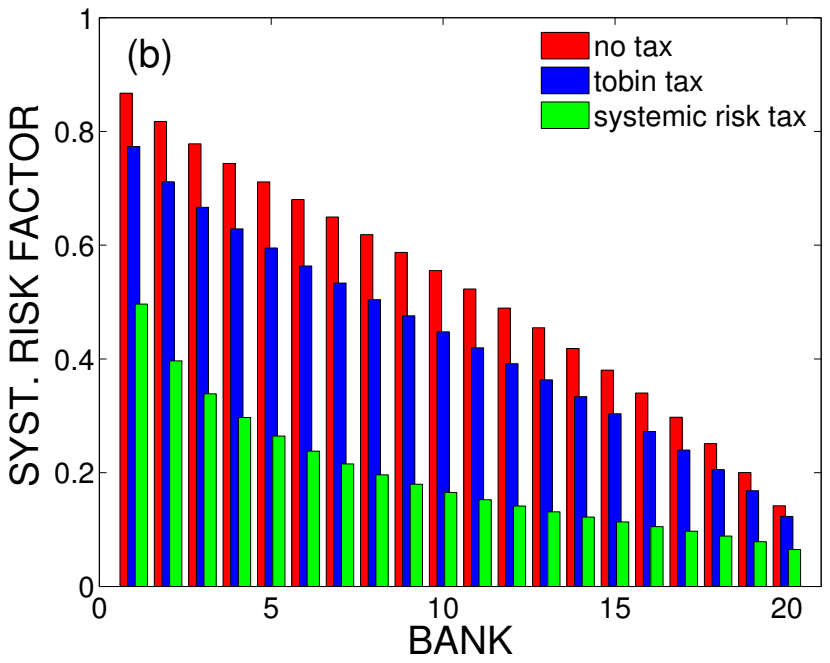
- No systemic risk management
- Systemic Risk Tax (SRT)
- Tobin-like tax

# Model results: Systemic risk profile

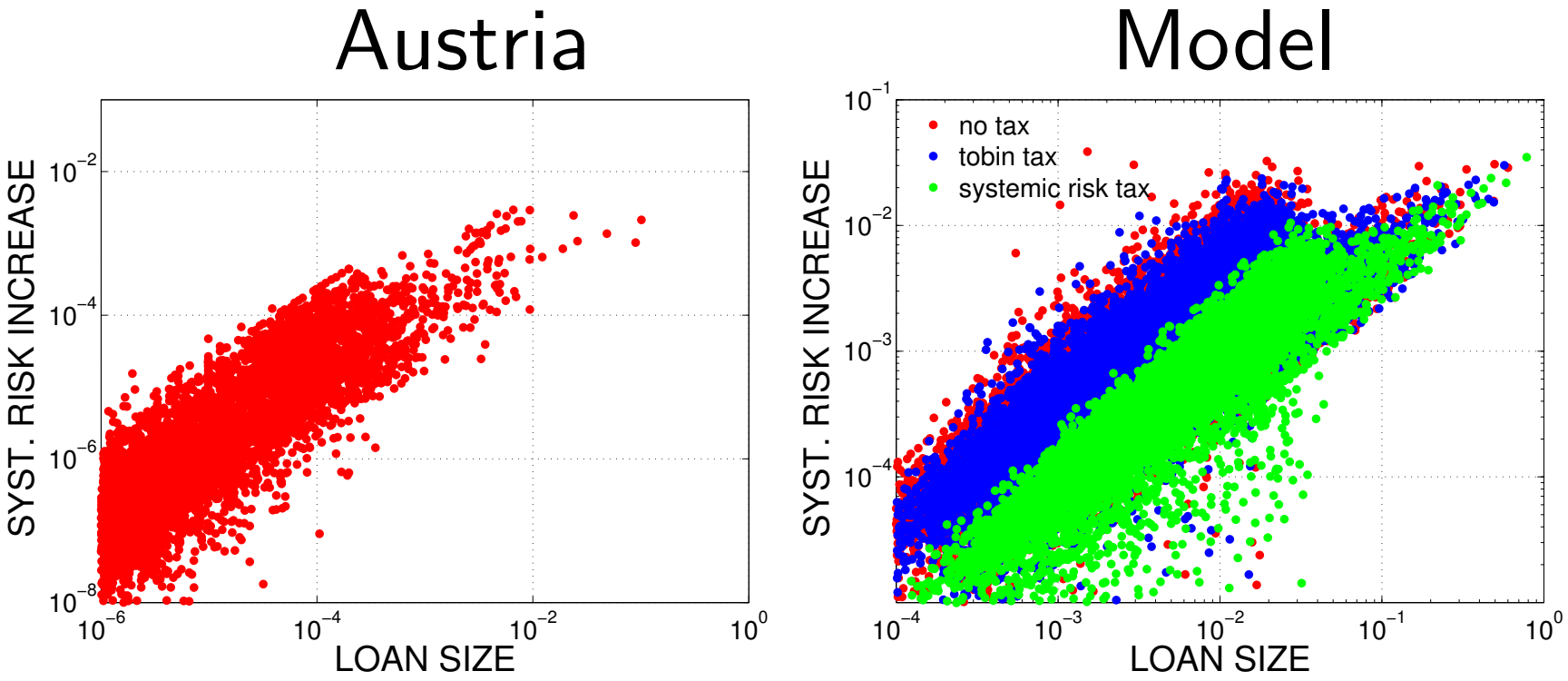
Austria



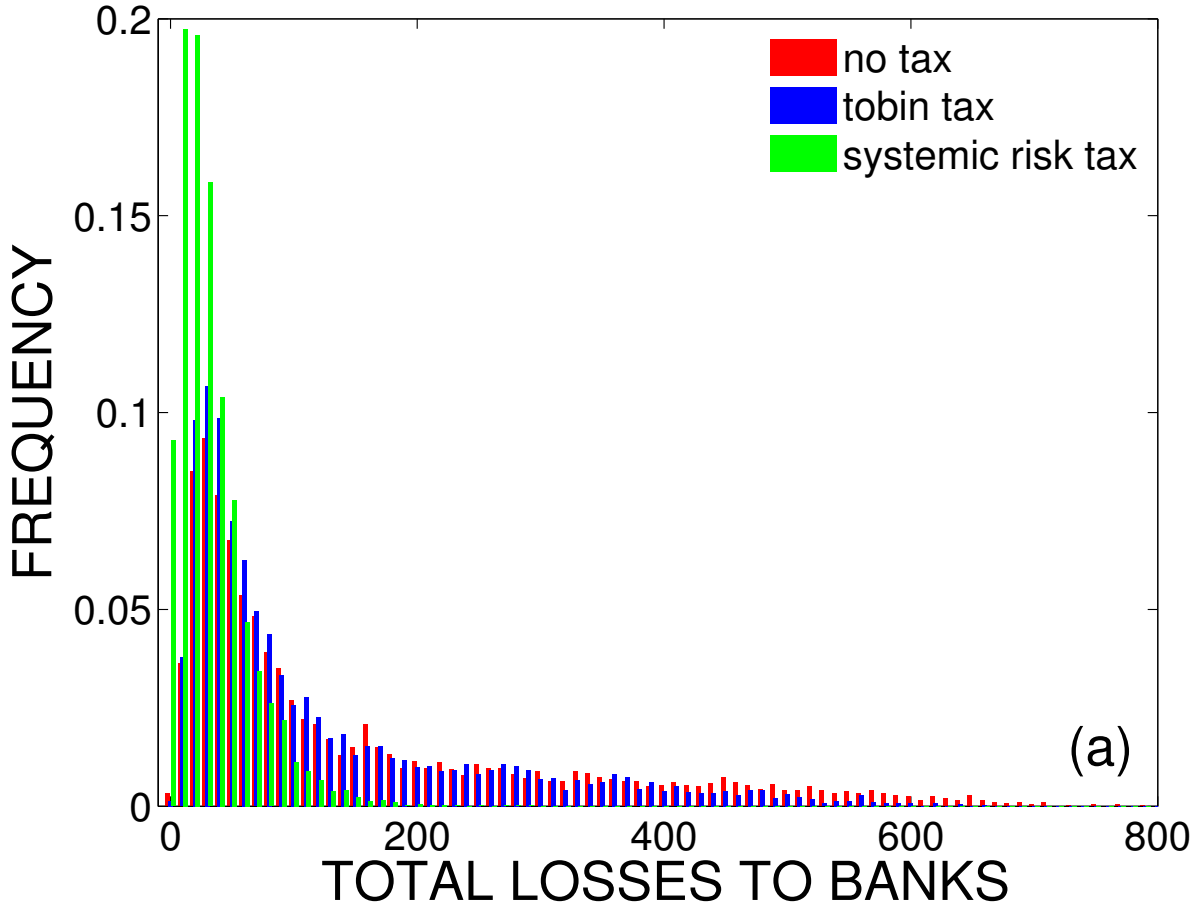

Model



# Model results: Systemic risk of individual loans

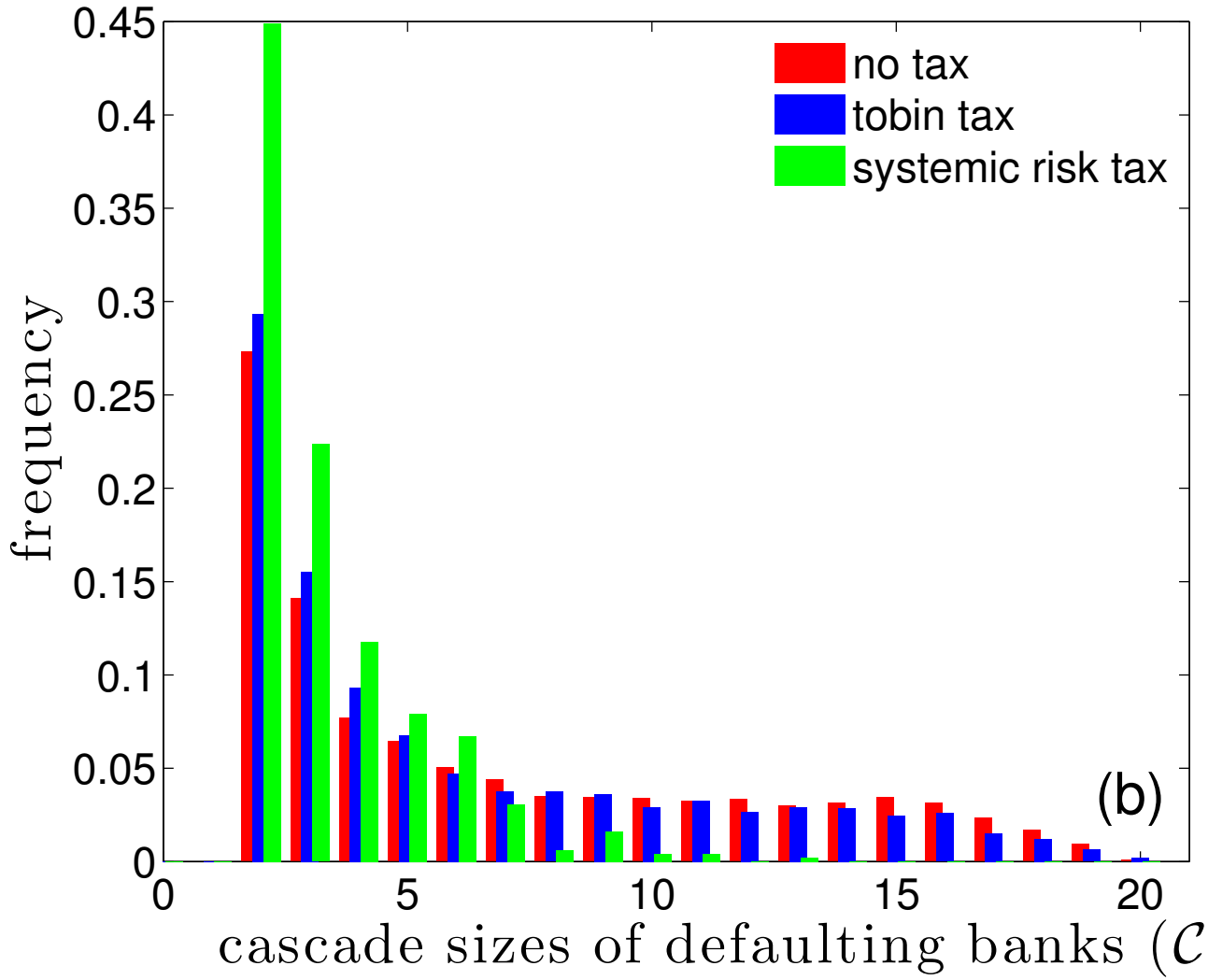


# Model results: Distribution of losses

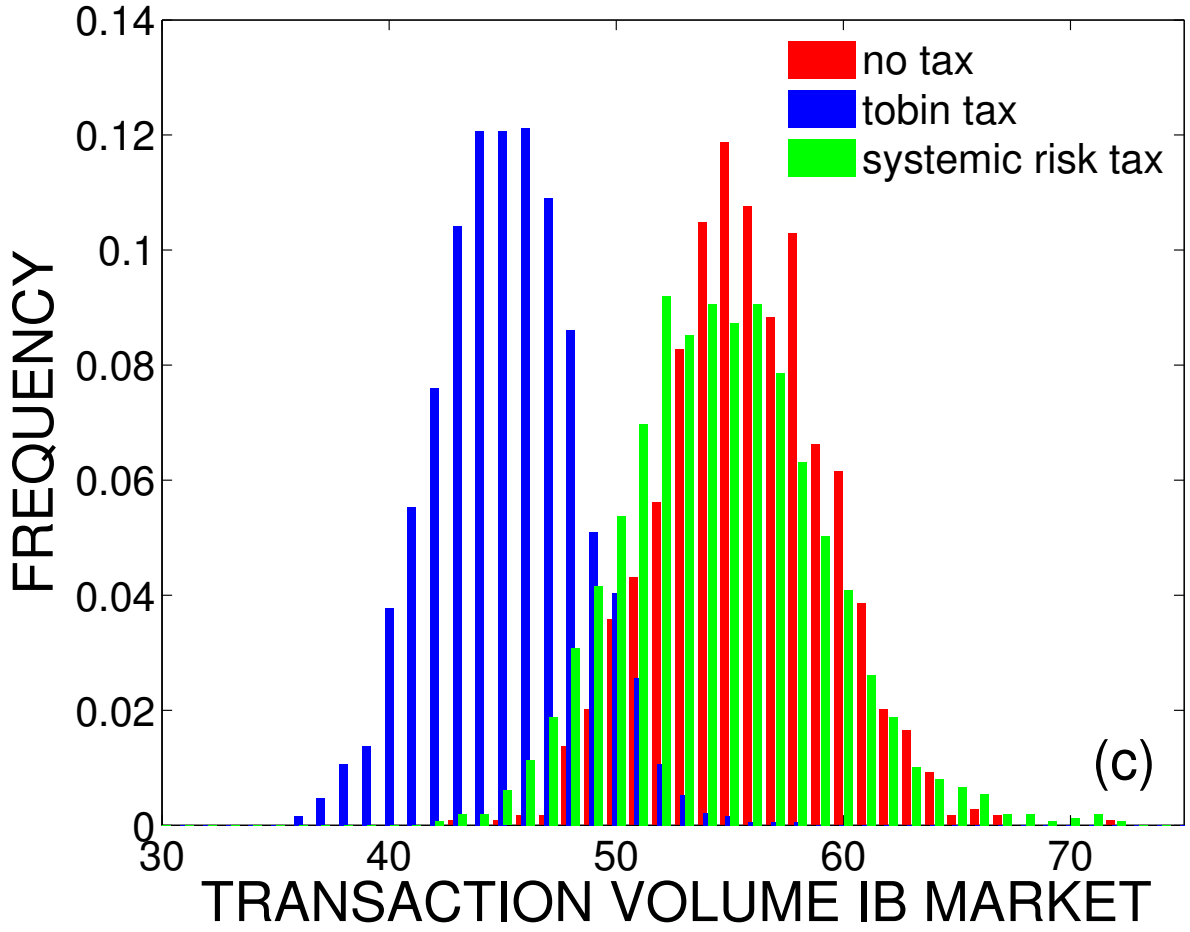



SRT eliminates systemic risk. How?

# Model results: Cascading is suppressed



# Model results: Credit volume




Tobin tax reduces risk by reducing credit volume

# Implementation in reality

- Bank $i$ requests loan of size $L_{ij}$ from bank $j$
- Bank $j$ provides loan for interest $I(L_{ij})$
- Central Bank computes SRT($L_{ij}$) for transaction
- Cost for loan with bank $j$: $I(L_{ij})$+SRT($L_{ij}$)
- Bank $i$ asks other bank $k$ for same transaction $L_{ik} = L_{ij}$
- Costs for loan with bank $k$: $I(L_{ik})$+SRT($L_{ik}$)
- Bank $i$ choses transaction partner for which costs are minimal

# Challenges – what could be wrong ?

- **SRT is pro-cyclical** – feedback: SRT hits most risky banks hardest. Needed: ramp-up phase. Once system is in low-risk equilibrium, there are practically no pro-cyclical effects

- **SRT is useless if not all countries participate** – arbitrage possibilities for non-participating countries – same as for any transaction tax

- **Basel III takes care of Systemic Risk?**

- **the interbank network is not the relevant one** – role of derivatives, mutual cross-holdings, overlapping pfs, etc. $\rightarrow$ apply SRT to other multiplex layers

Mathematical proof:

SR-free equilibrium under SRT exists

# Basel III

# Basel III

• Indicator approach: **five categories** (equal weights $\omega^i$): size, interconnectedness, financial institution infrastructure, cross-jurisdictional activity and complexity. Sub-indicators (equal weights)

$$S_j = \sum_{i \in I} \omega^i \frac{D_j^i}{\sum_j^B D_j^i} 10,000$$

| Bucket | Score range | Bucket thresholds | Higher loss-absorbency requirement |
|---|---|---|---|
| 5 | D-E | 530-629 | 3.50% |
| 4 | C-D | 430-529 | 2.50% |
| 3 | B-C | 330-429 | 2.00% |
| 2 | A-B | 230-329 | 1.50% |
| 1 | Cutoff point-A | 130-229 | 1.00% |

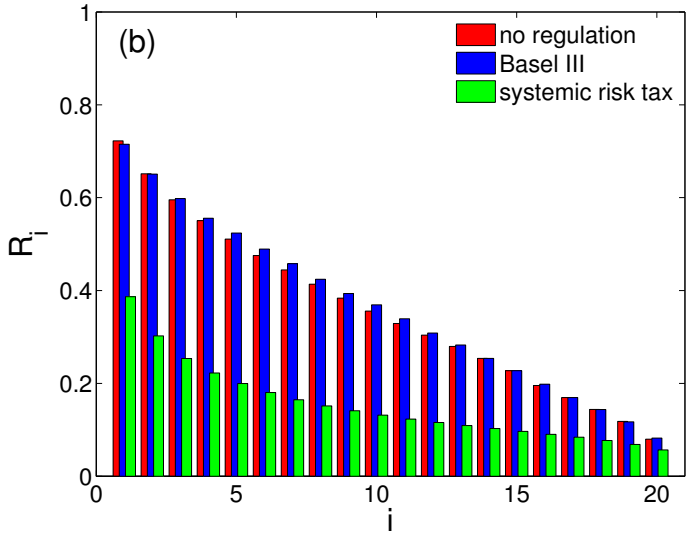
- **Cross-jurisdictional activity** (20%)
- **Size** (20%)
- **Interconnectedness** (20%)
- **Substitutability / financial institution infrastructure** (20%)
- **Complexity** (20%)

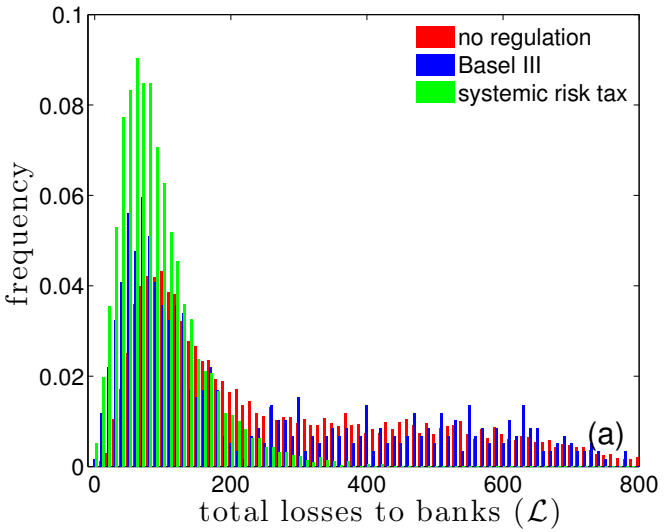
| | |
|---|---|
| Cross-jurisdictional claims | 10% |
| Cross-jurisdictional liabilities | 10% |
| Total exposures for use in Basel III leverage ratio | 20% |
| Intra-financial system assets | 6.67% |
| Intra-financial system liabilities | 6.67% |
| Securities outstanding | 6.67% |
| Assets under custody | 6.67% |
| Payments activity | 6.67% |
| Underwritten transactions in debt and equity markets | 6.67% |
| (Notional) OTC derivatives | 6.67% |
| Level 3 assets | 6.67% |
| Trading and available-for-sale securities | 6.67% |

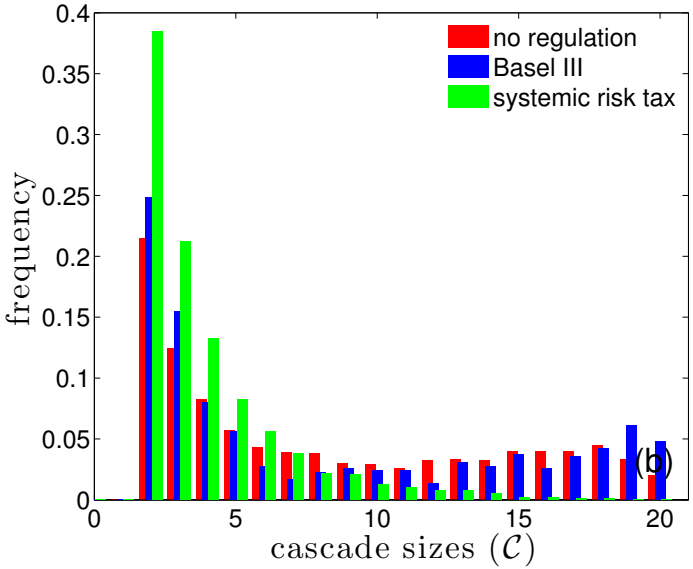
# Basel III

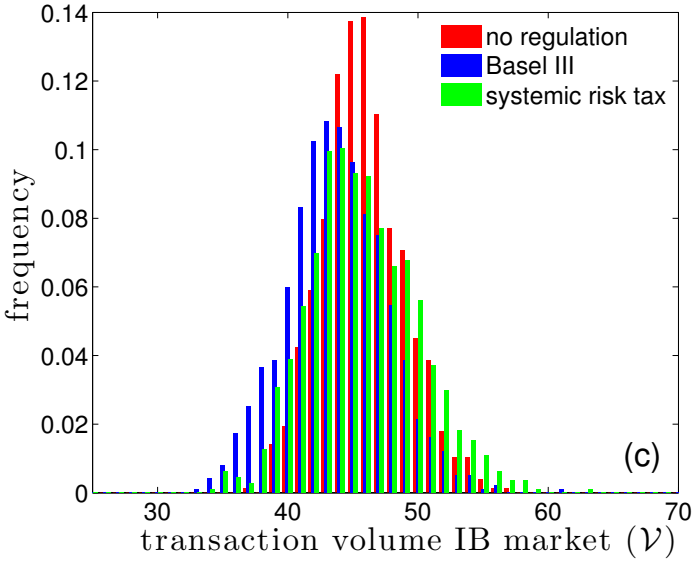
- **Size:** total exposures of banks
- **Interconnectedness:** use directed and weighted networks
- **Substitutability/ financial institution infrastructure:** payment activity of banks. The payment activity is measured by the sum of all outgoing payments of banks.
- **Complexity:** not modelled (weight 0)
- **Cross-jurisdiction activity:** not modelled (weight 0)

# Basel III is does not reduce SR !

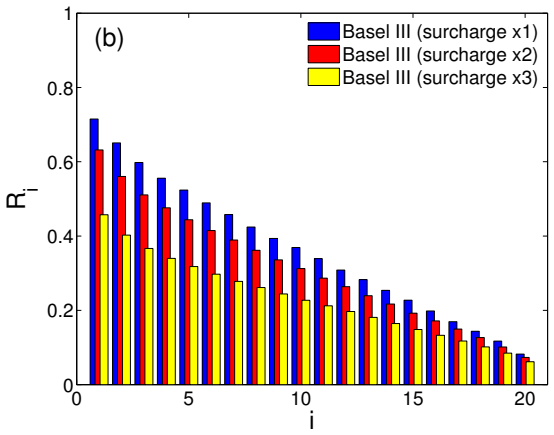


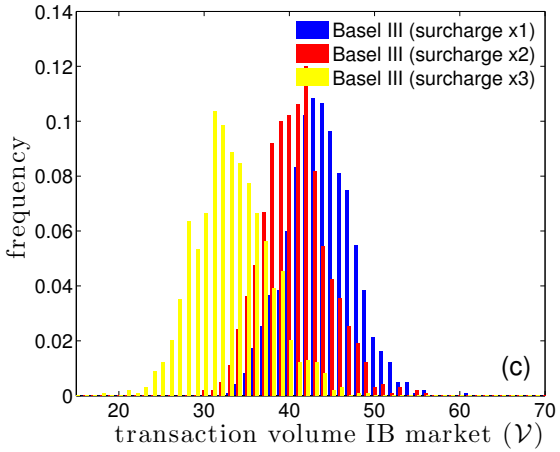



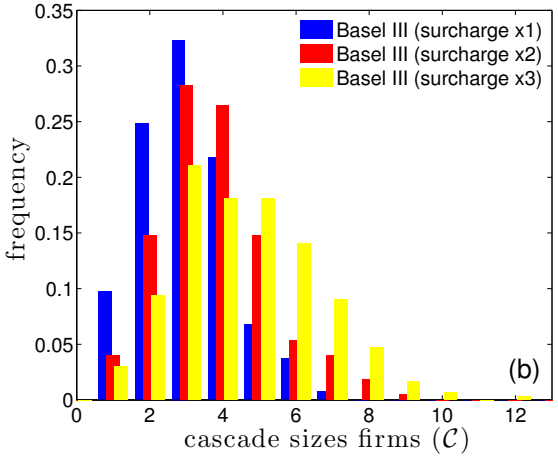



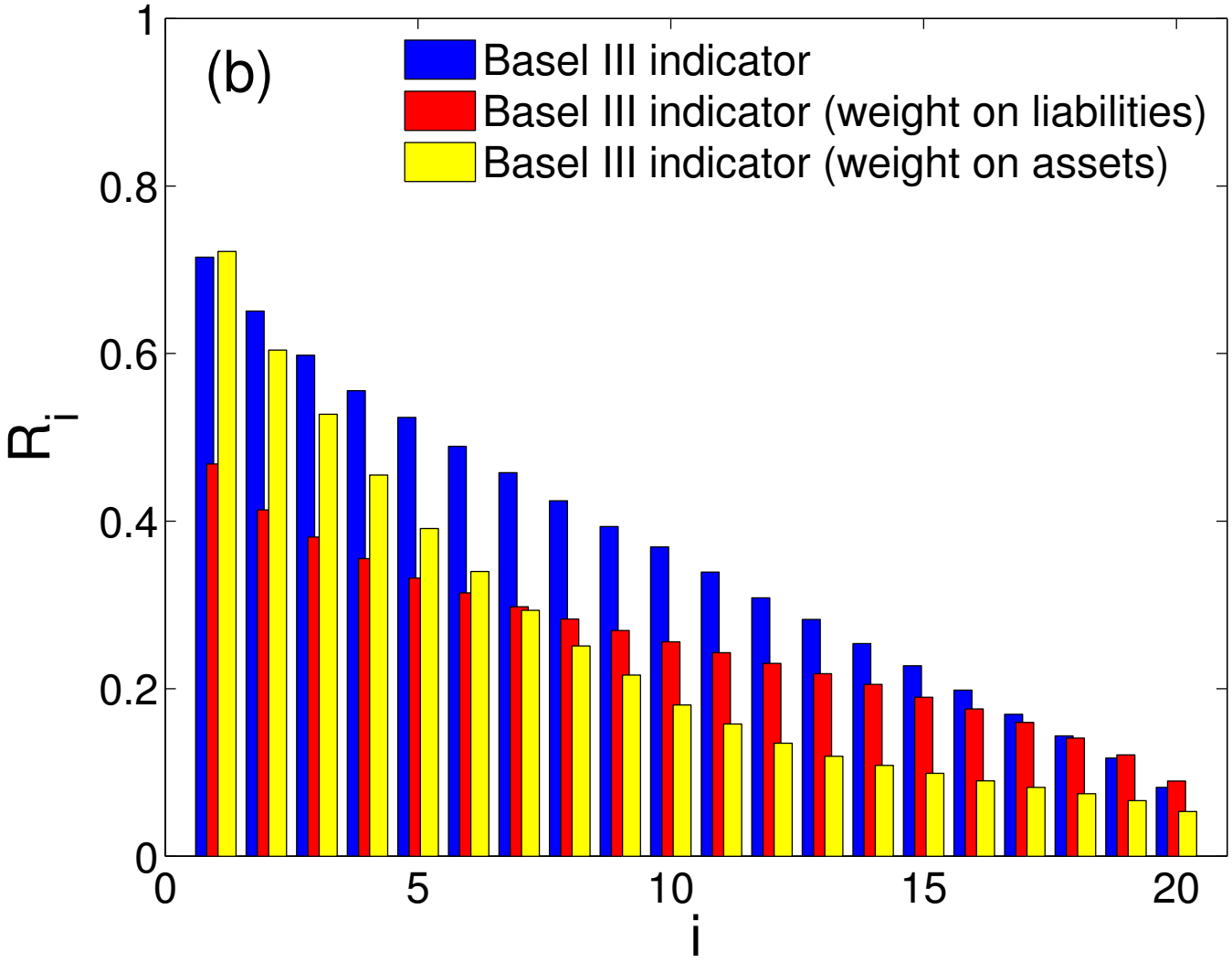
# Basel III works under tremendous costs



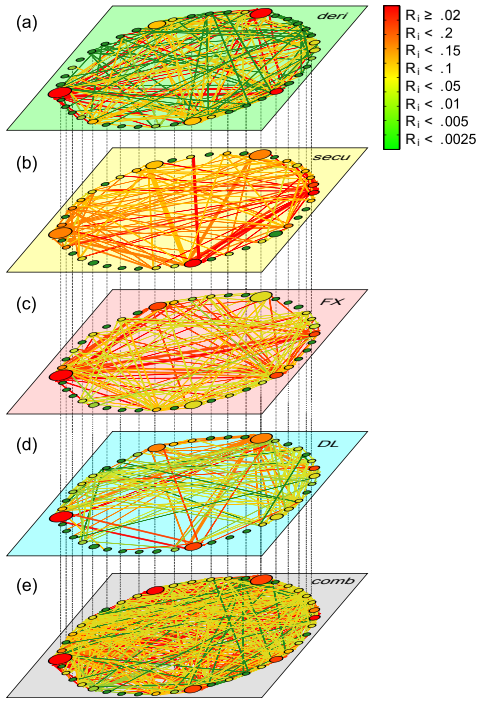



# Basel III re-distributes systemic risks



# Part III: Financial multiplex networks

# Systemic risk multiplex of Mexico Sep 30 2013




layer 1: derivatives network

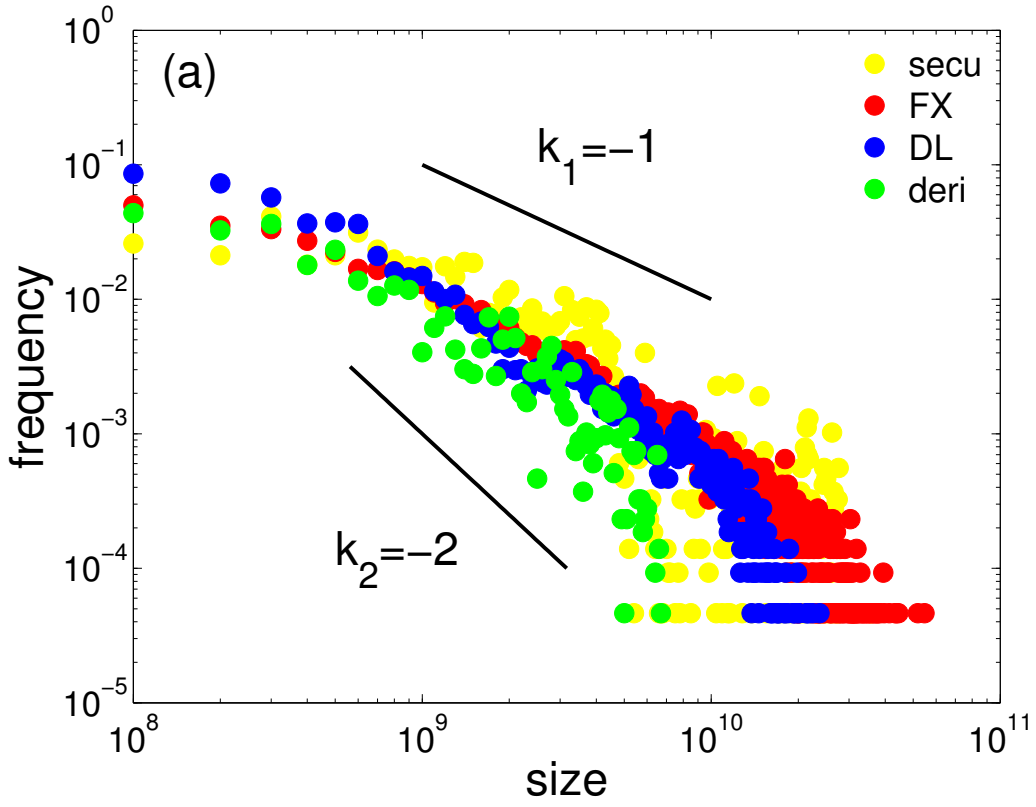
layer 2: network of cross holdings

layer 3: foreign exchange exposures

layer 4: network of deposits and loans

layer 5: combined exposures

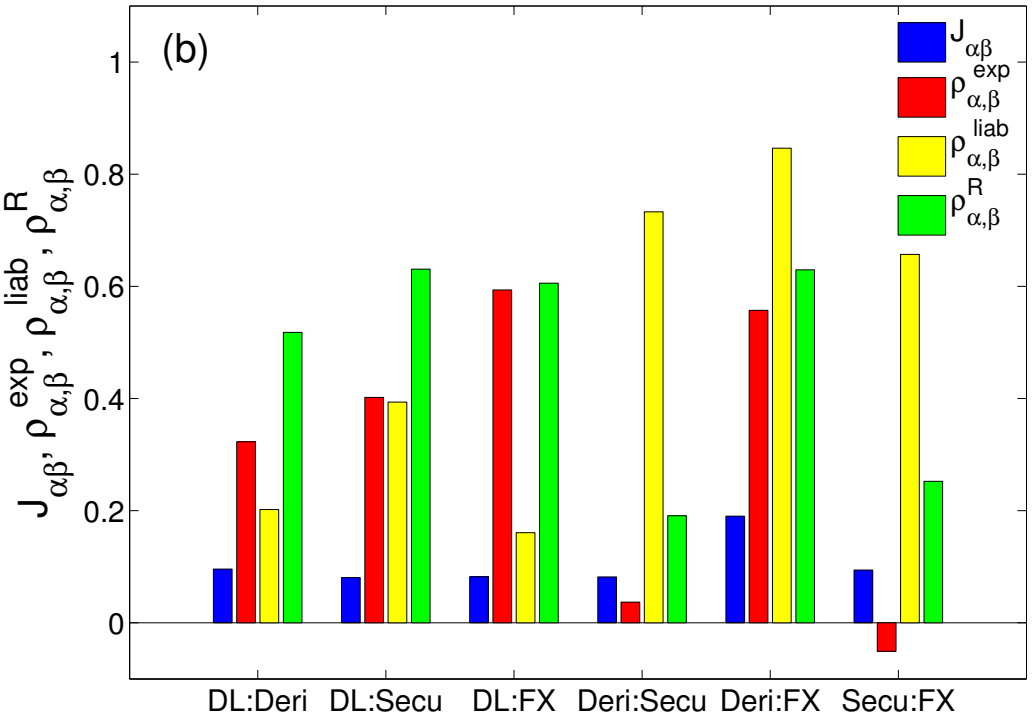
# Size of exposures in the various layers




distribution of exposure size (in Mex $) distribution

data aggregated over Jan 2 2007 to May 30 2013

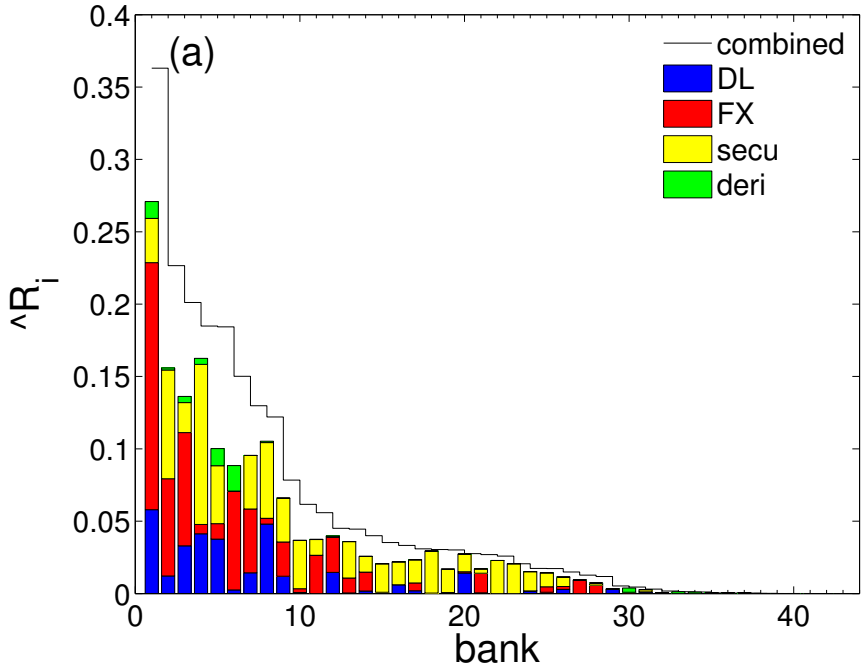
# Interactions between layers (markets)




**Jaccard coefficient:** $J_{\alpha\beta}$

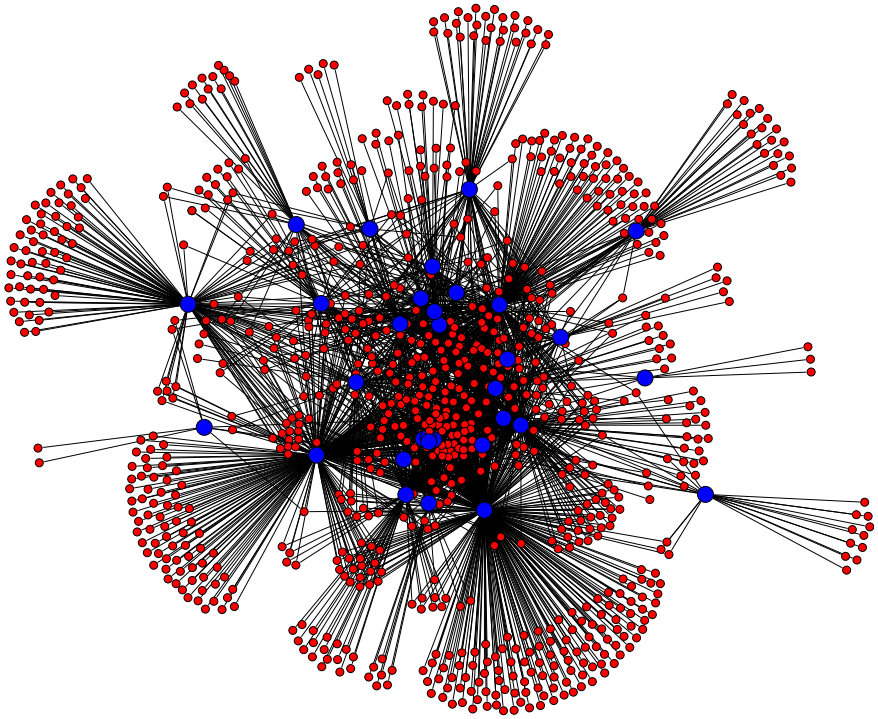
**correlations:** exposure $\sum_i L^{\alpha}_{ij}$, liabilities $\sum_j L^{\alpha}_{ij}$, DebtRank $R$

# Risk profile in the various layers



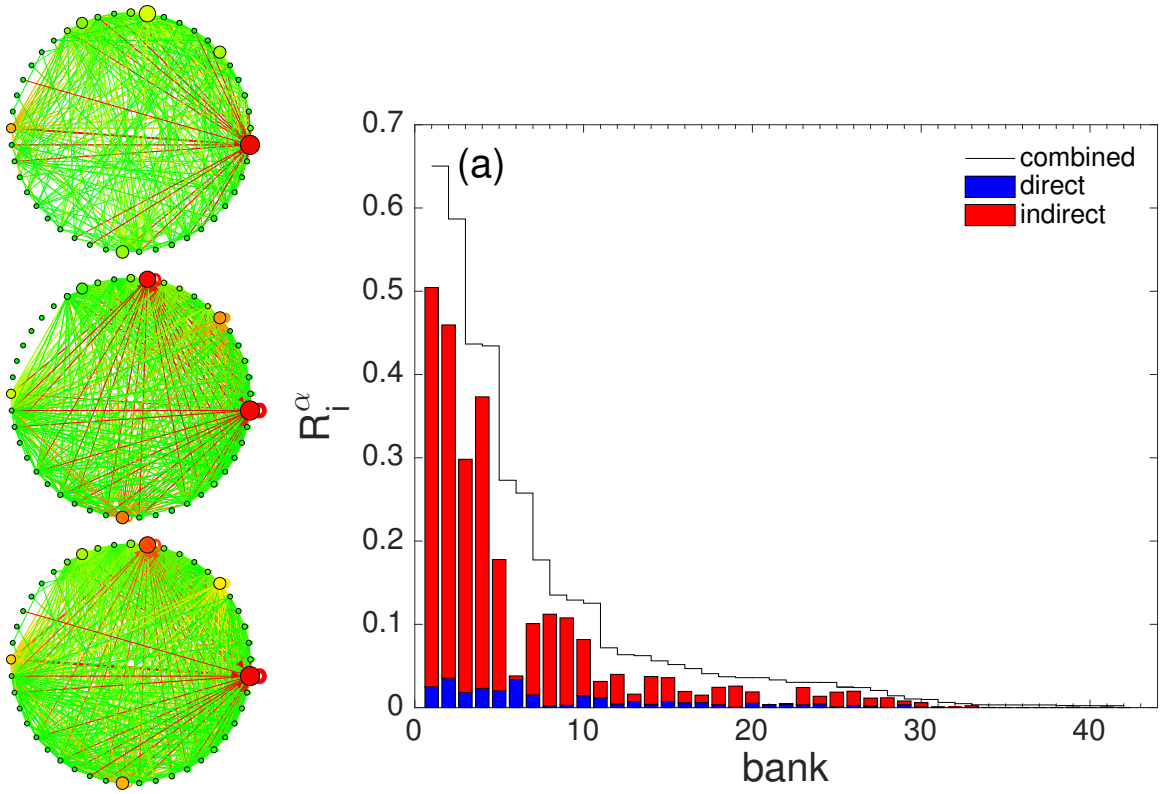

systemic risk profile for different layers
DebtRank $\hat{R}_i^{\alpha}$ stacked for banks. Jan 2, 2007 – May 30, 2013

# Overlapping portfolios

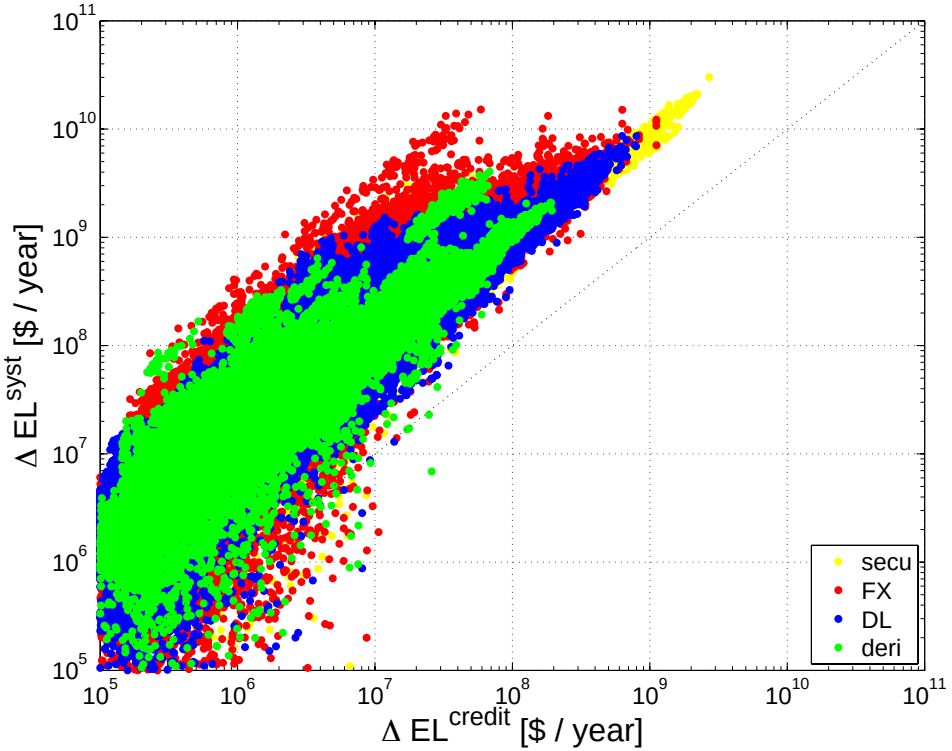


banks ... blue, assets ... red

# Overlapping portfolios (preliminary)



# Expected systemic losses for every transaction




$\Delta EL^{\text{syst}} > \Delta EL^{\text{credit}} \rightarrow$ defaults **do not affect lender only** but involves third parties (all exposures 2007–2013)

# Conclusions

- systemic risk is a network property – endogenously created
- can be measured for each institution / transaction: DebtRank
- can be eliminated by SRT; networks don't allow for cascading
- SRT should **not be payed!** – evasion re-structures networks
- SRT does not reduce credit volume; re-ordering transactions
- Basel III as planned does not work – 3 fold works – costly
- SR requires a multiplex network framework
- Expected Systemic Loss Index: compare countries, over time
- SR tax is technically feasible

# Mexican data collaborators

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Marco van der Leij

# Alternatives to systemic risk tax

- Mandatory CDS

- Markose: taxes banks – not transactions – according to eigenvalue centrality

**Problem 1** eigenvector is not economically reasonable number

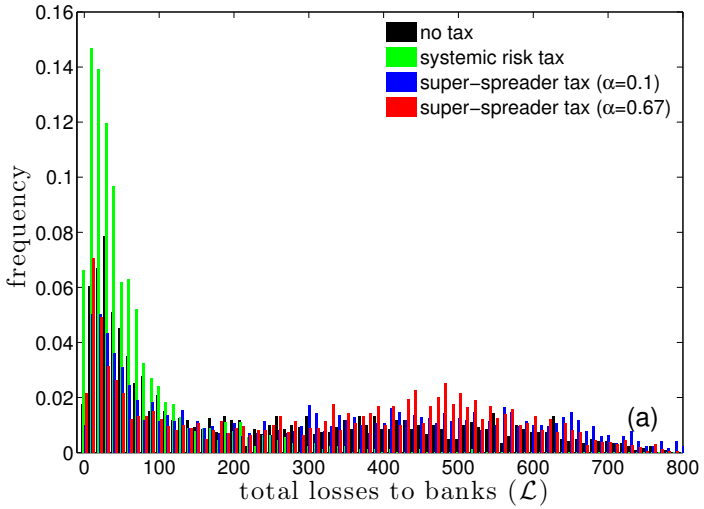
**Problem 2** blind to cycles in contract networks

**Problem 3** absurd size (up to 30% of capital)

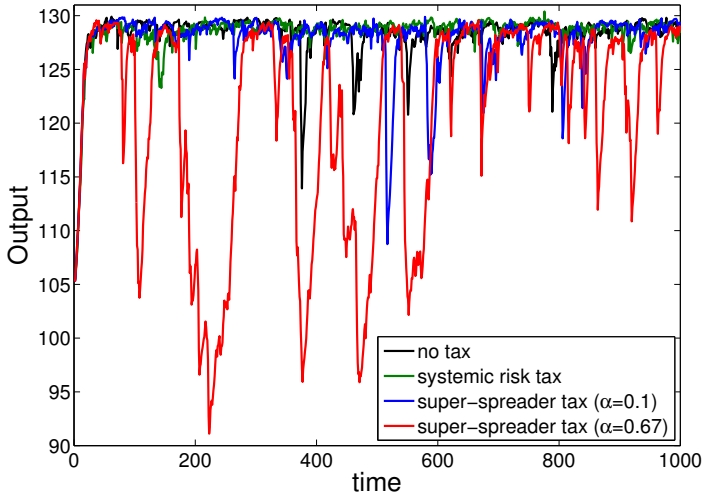
- Tax size: misses small SR institutions, SR improvement at tremendous economic cost

# Markose proposal in macro-financial ABM

Losses




Output (GDP)




| | No tax | SRT | SST (α=0.1) | SST (α=0.67) |
|---|---|---|---|---|
| Output | 128.458 ± 1.792 | 128.382 ± 2.038 | 127.506 ± 3.278 | **106.877 ± 20.706** |
| Unemployment | 0.0017 ± 0.0102 | 0.0020 ± 0.0121 | 0.0059 ± 0.0204 | **0.1520 ± 0.1533** |
| Credits (firms) | 128.174 ± 18.990 | 121.435 ± 17.303 | 120.193 ± 19.397 | **87.943 ± 29.958** |
| Interest (firms) | 0.0238 ± 0.0015 | 0.0243 ± 0.0016 | 0.0241 ± 0.0017 | **0.0248 ± 0.0023** |

# Statistical measures

- CoVAR: descriptive – not predictive!
- SES, SRISK: related to leverage and size
- DIP: market based – markets do not see NW-based SR

**pro** data publicly available, easy to implement

**contra** 'conditional' hard to define without knowledge of networks, descriptive, non-predictive