Quantification of systemic risk from overlapping portfolios in the financial system

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Systemic risk

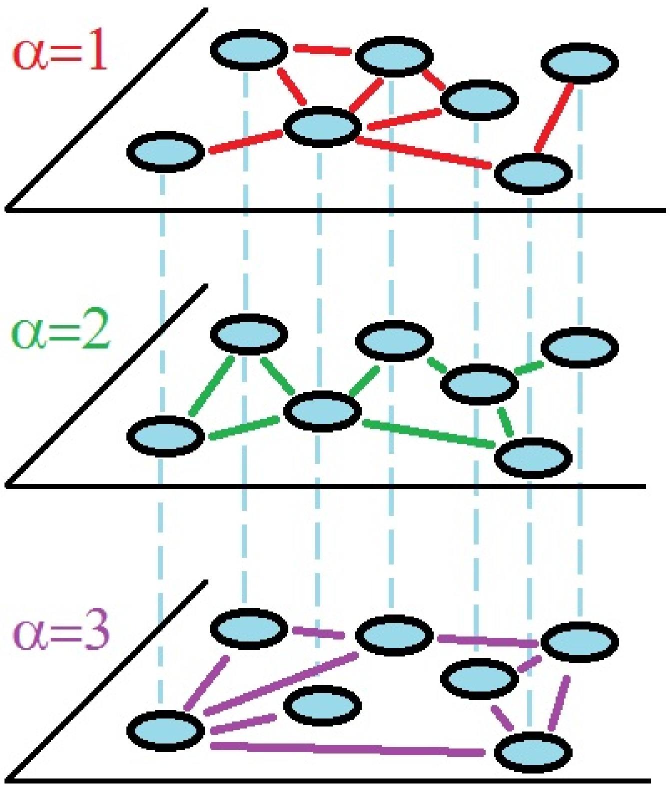
- risk that significant fraction of financial network defaults
- systemic risk is **not** the same as default risk
- systemic risk is **not** the same as economic risk
- banks care about credit-default risk
- banks have no means to manage systemic risk

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

Two origins of systemic risk

- **synchronisation of behaviour**: herding, fire sales, margin calls, various amplification effects – may involve networks
- **networks of contracts**: this is what the financial system is

Systemic risk is created on multiplex networks



layer 1: lending–borrowing loans

layer 2: derivative networks

layer 3: collateral networks

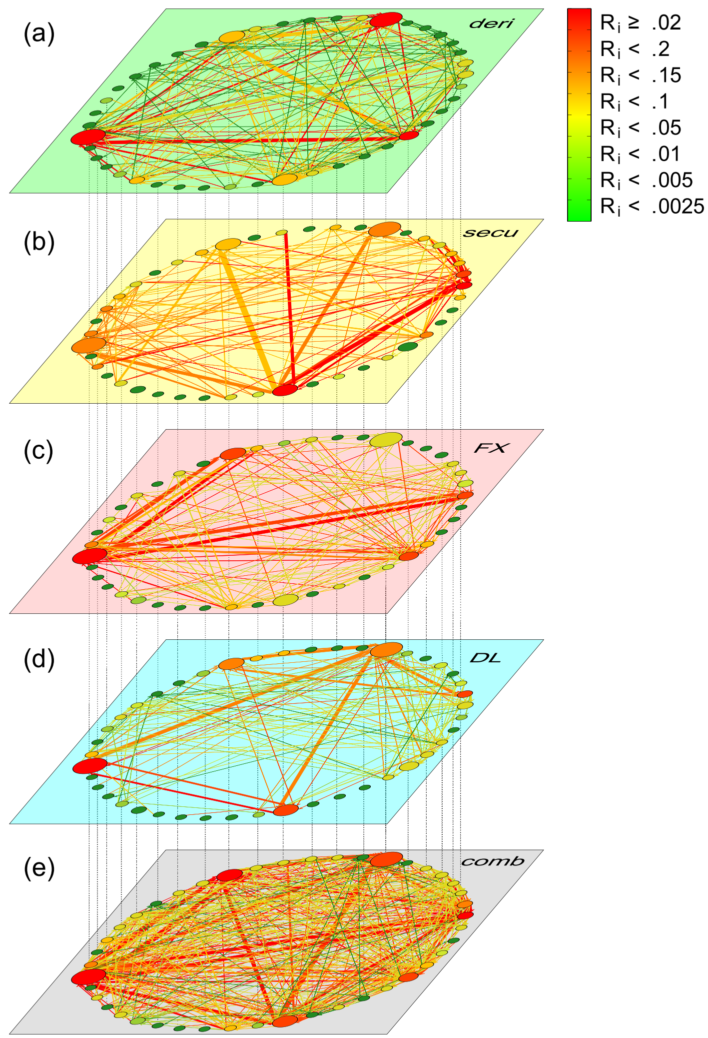
layer 4: securities networks

layer 5: cross-holdings

layer 6: overlapping pfolios

layer 7: liquidity: over-night loans

layer 8: FX transactions

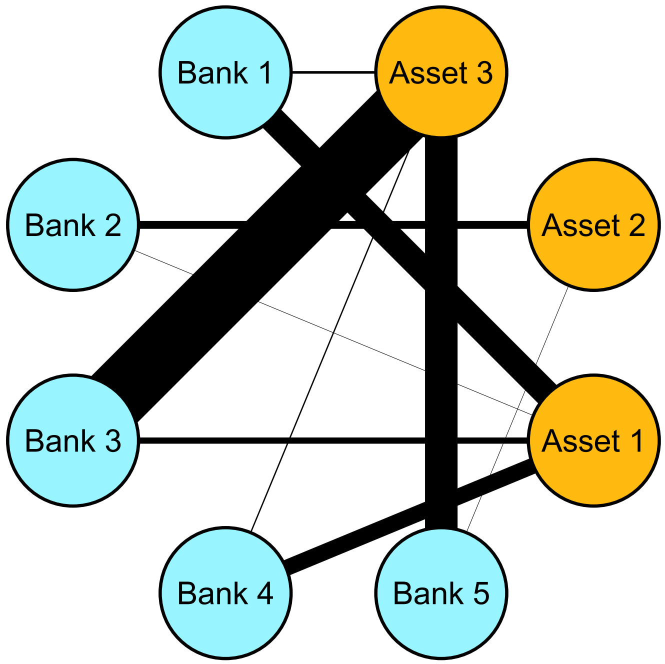

(a)
deri
(b)
secu
(c)
FX
(d)
DL
(e)
comb
$R_i \geq .02$
$R_i < .2$
$R_i < .15$
$R_i < .1$
$R_i < .05$
$R_i < .01$
$R_i < .005$
$R_i < .0025$

Different exposure types

- interbank lending: deposits and loans
- security cross-holdings: bank i holds securities of bank j
- derivatives
- foreign exchange (settlement risk)
- overlapping portfolios $\rightarrow$ indirect exposure

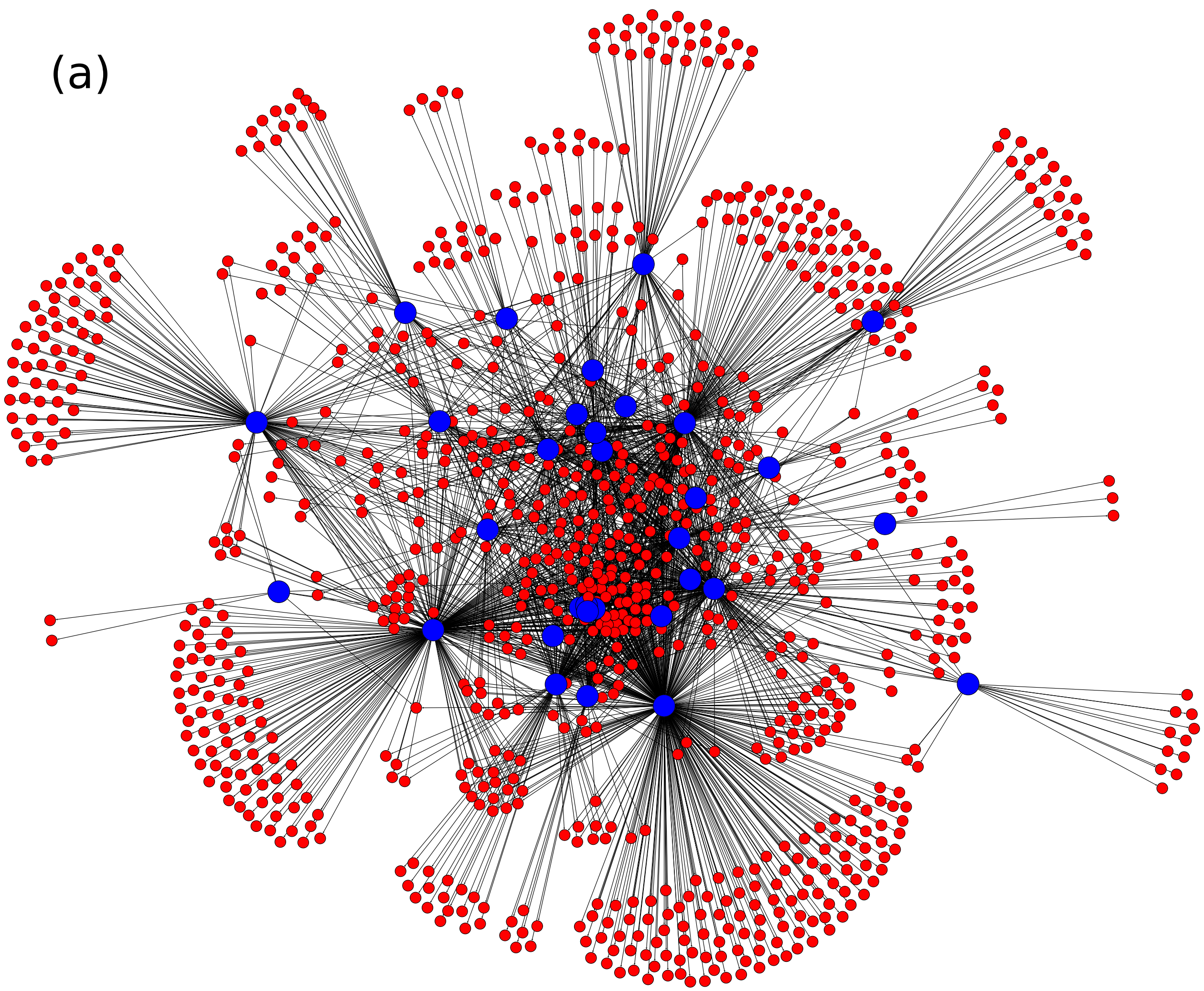
for Mexican data: exposures are known on daily level

Exposure from overlapping portfolios



Overlapping portfolios in Mexican banks

(a)



Market depth and linear price impact

- market depth $D_k = c\,\frac{\langle \mathrm{vol}_k \rangle_{\mathrm{day}}}{\sigma_k}$
- total portfolio value of bank i, $S_i = \sum_k S_{ki} p_k$

If bank i sells S_{ki} of asset k, price is depressed by $\frac{S_{ki}}{D_k}$

If bank j owns S_{kj} of asset k $\rightarrow$ face loss of $S_{kj} \frac{S_{ki}}{D_k}$

$$\rightarrow \; X_{ij}^{\mathrm{OP}} = \sum_{k=1}^{K} S_{kj} S_{ki} \frac{1}{D_k}$$

Quantification of SR

Systemic risk – quantification

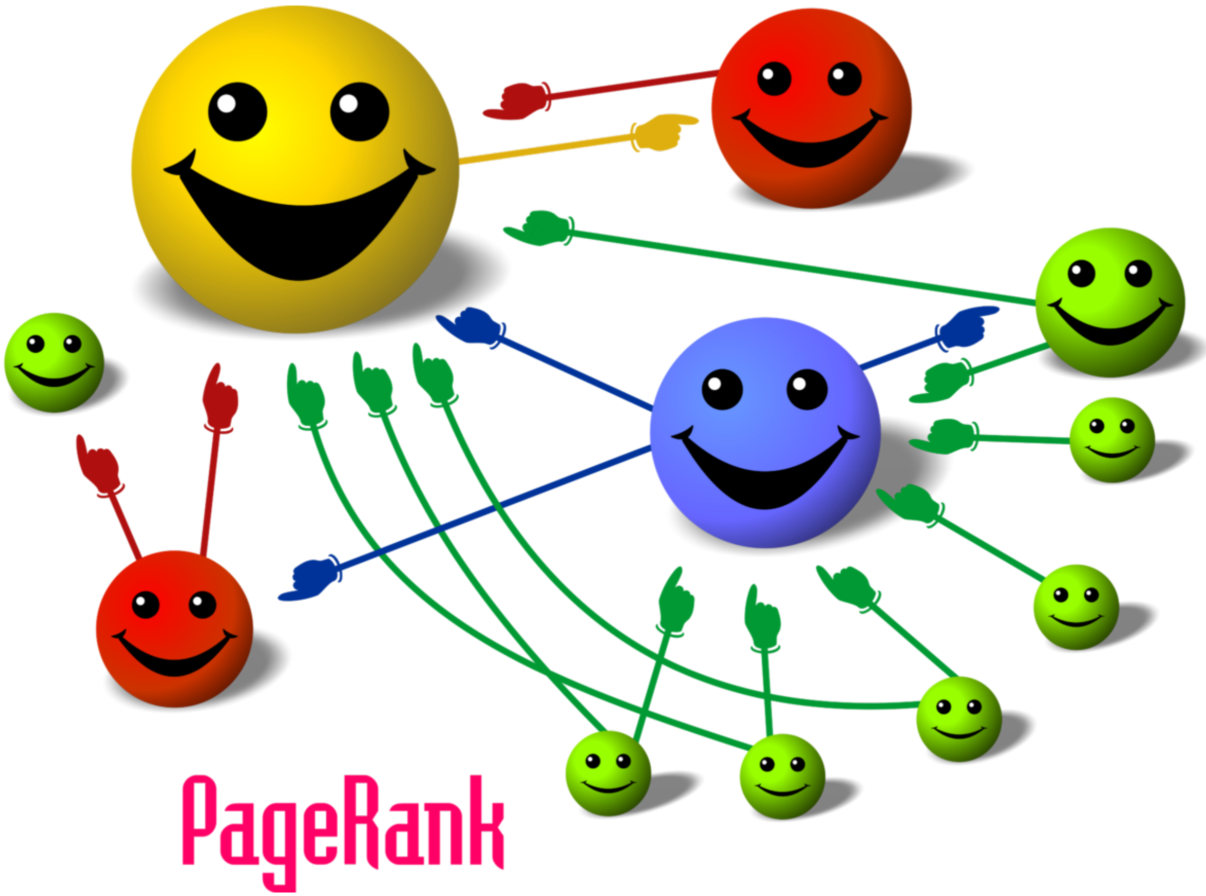
Wanted: systemic risk-value for every financial institution

given: entire network

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



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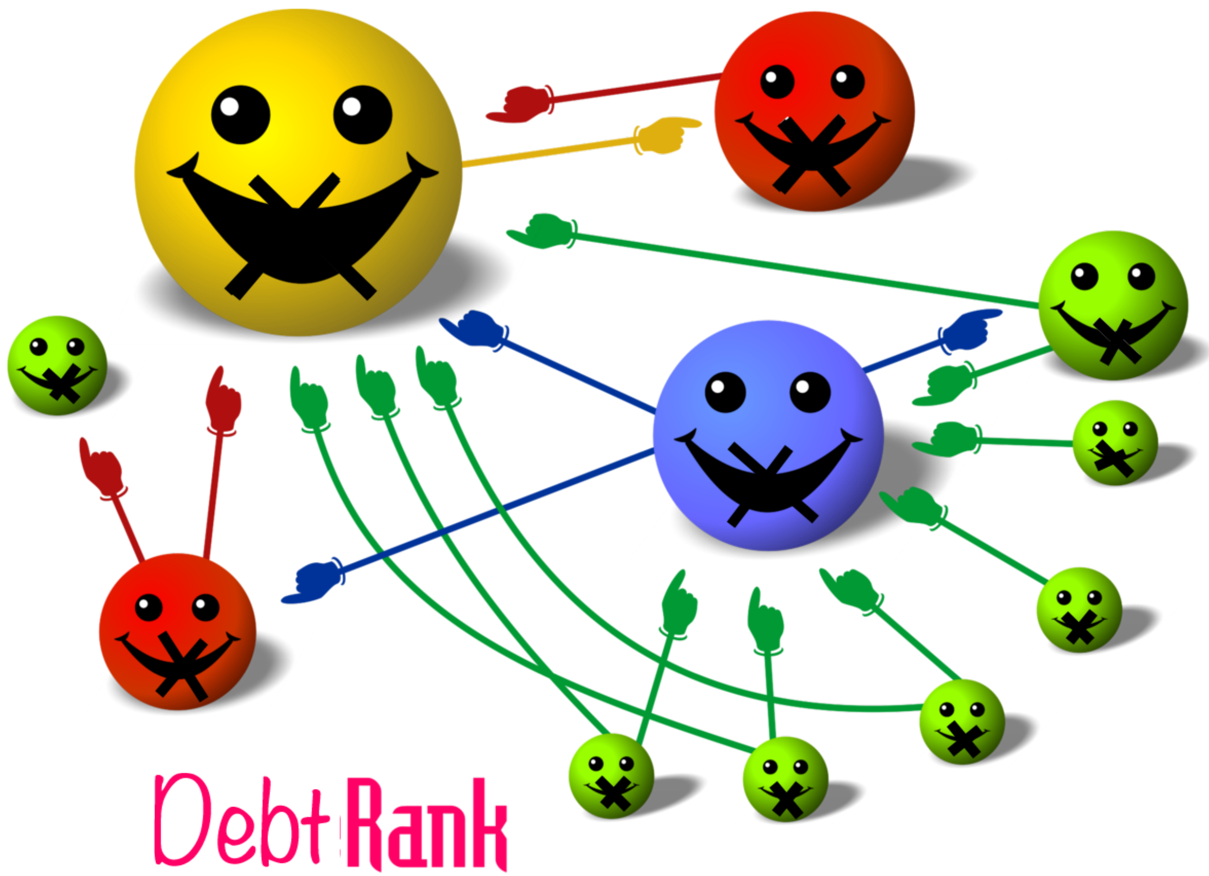
institution system. risky if system. risky institutions lend to it



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?

- **economic value** in network that is affected by node's default
- capitalization/leverage of banks taken into account
- cycles taken 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

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

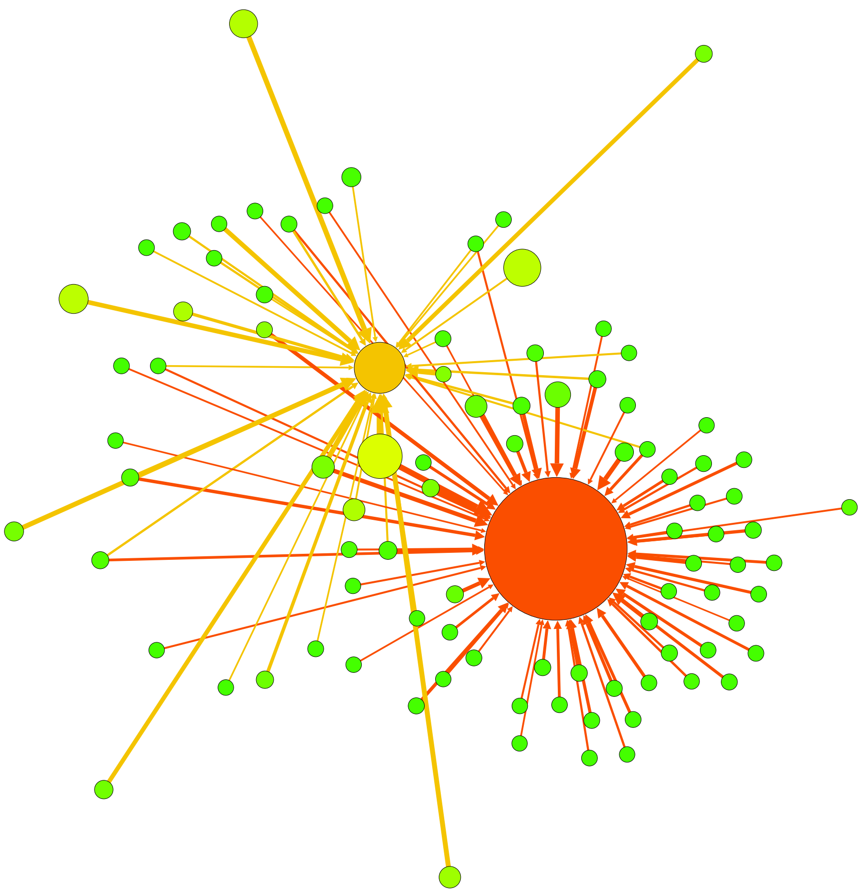
Systemic risk of nodes

Input: Network of contracts between banks

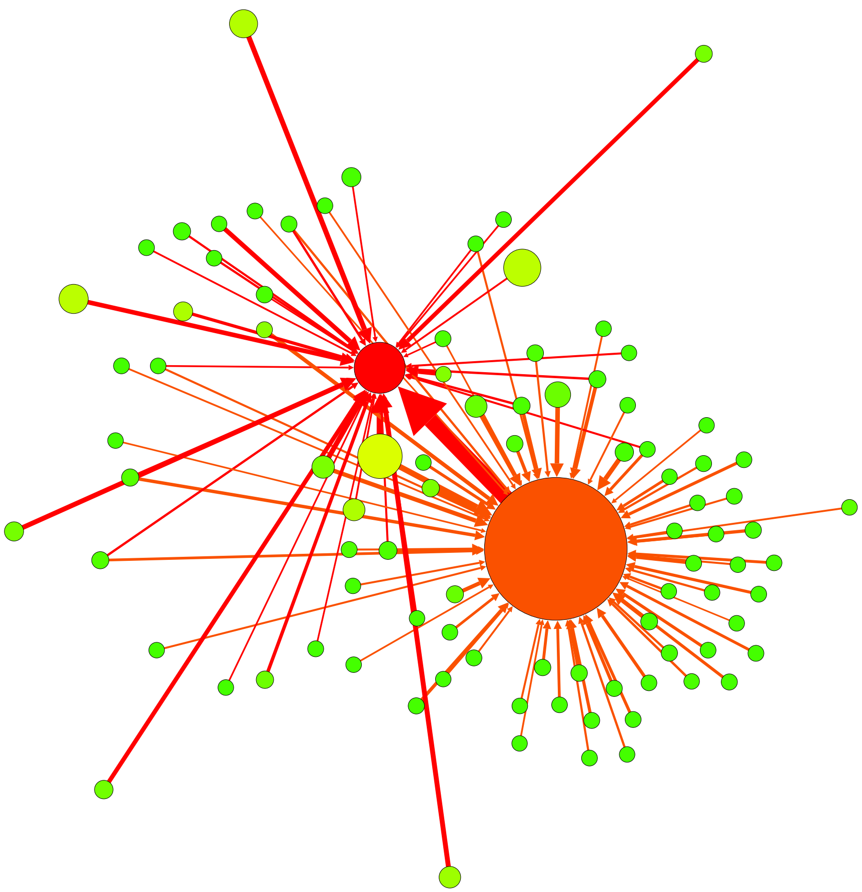
Compute = DebtRank; think of a complicated first eigenvector

Output: all banks i get damage value R_i (% of total damage)

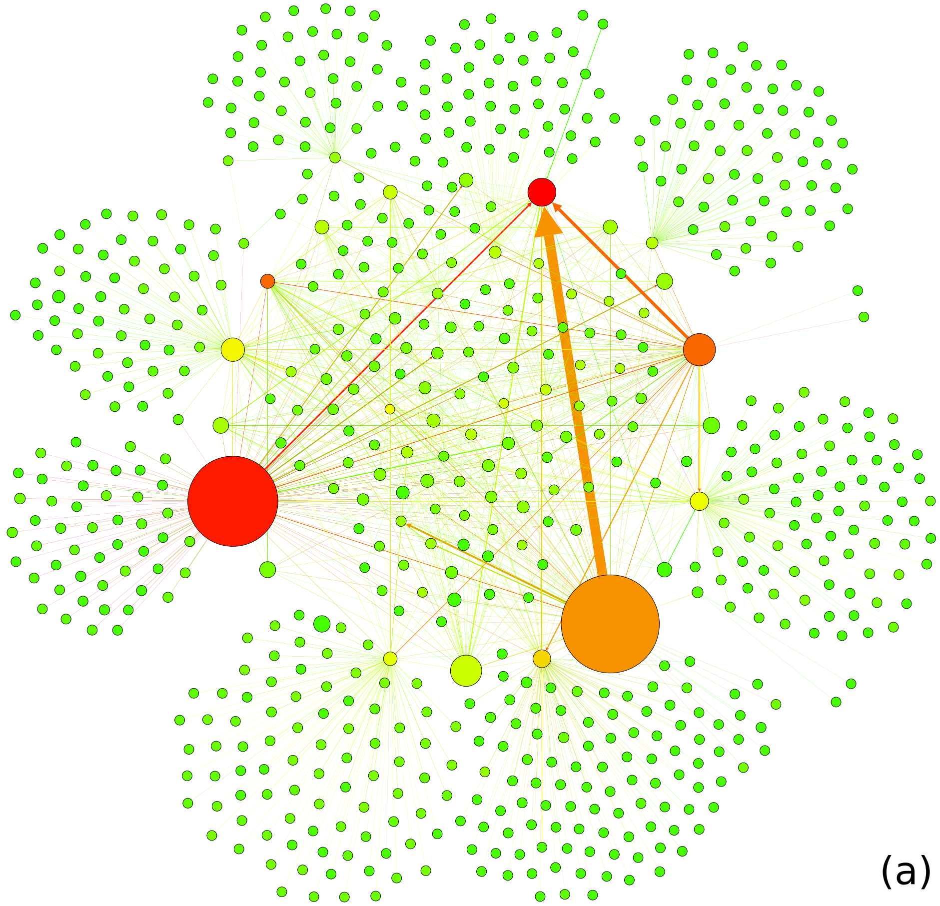
Systemic risk spreads by borrowing



Systemic risk spreads by borrowing



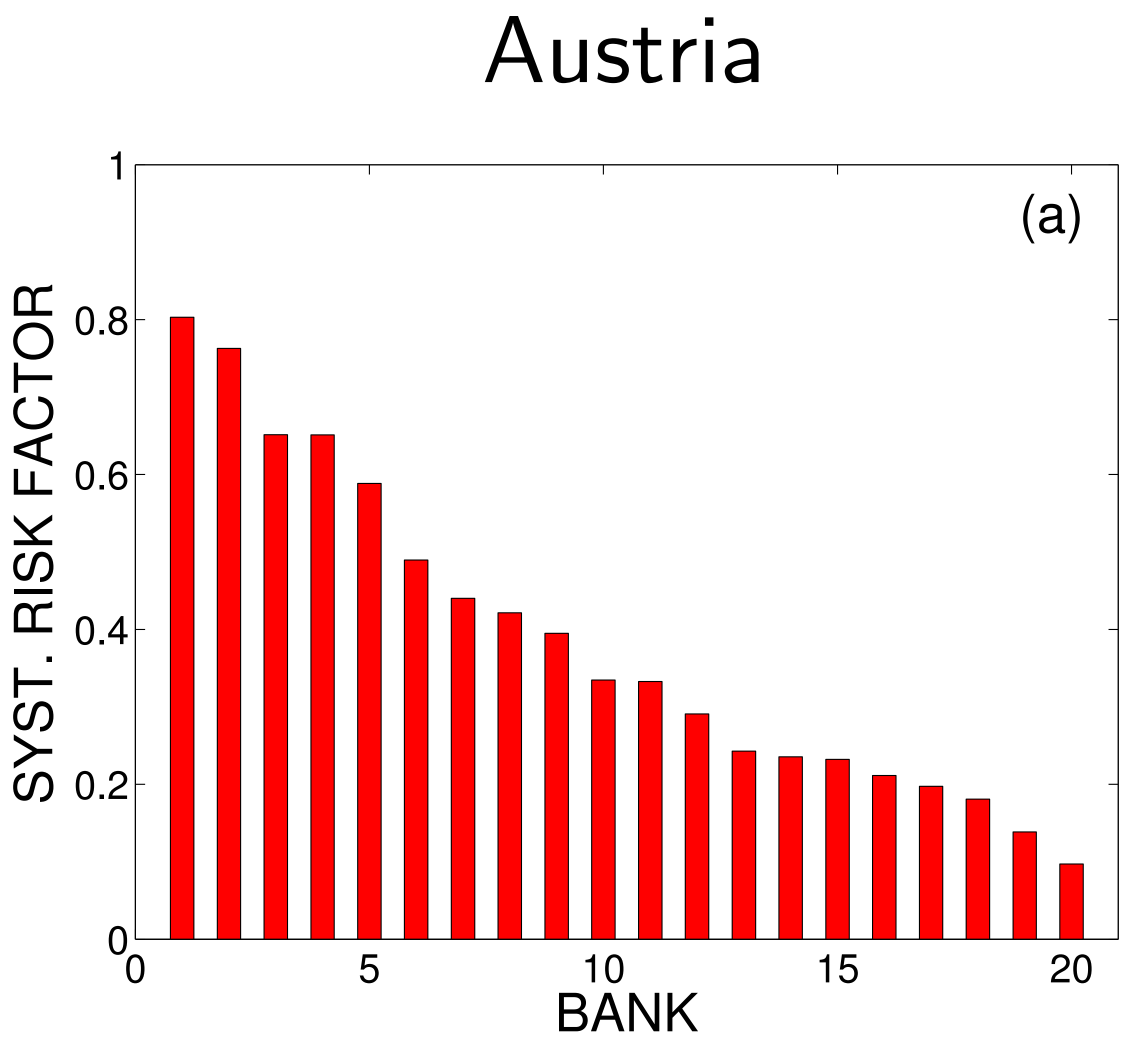
DebtRank Austria Sept 2009



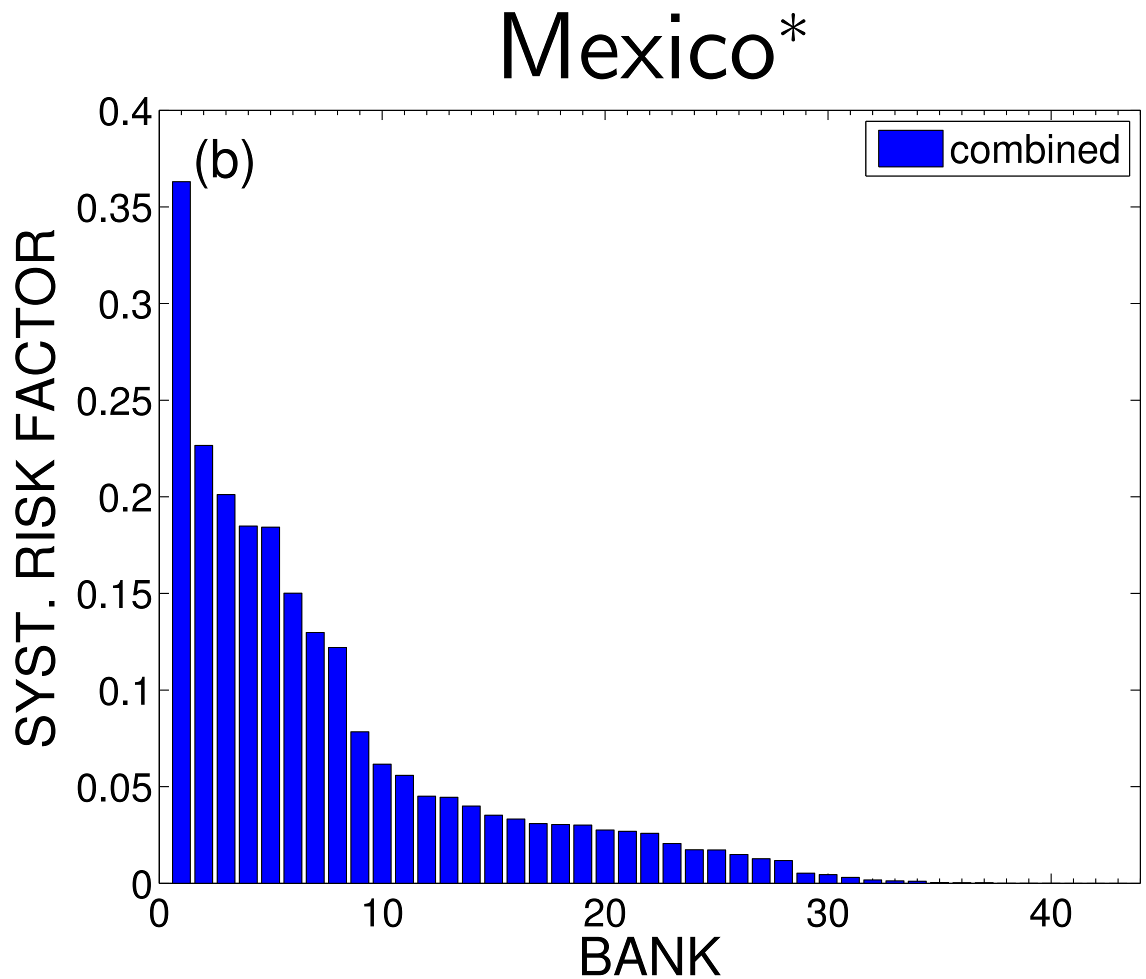
note: size is not proportional to systemic risk

note: core-periphery structure

Systemic risk profile

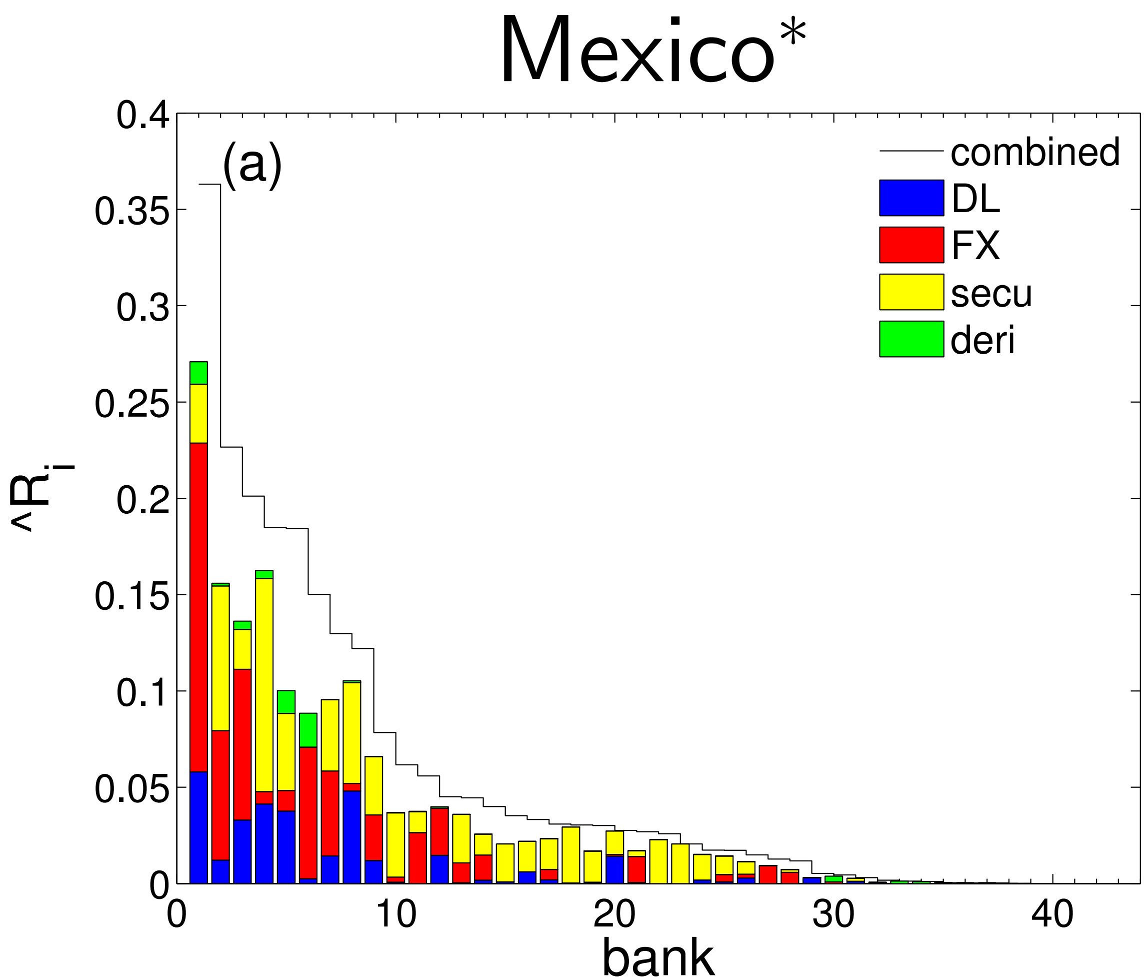


Systemic risk profile



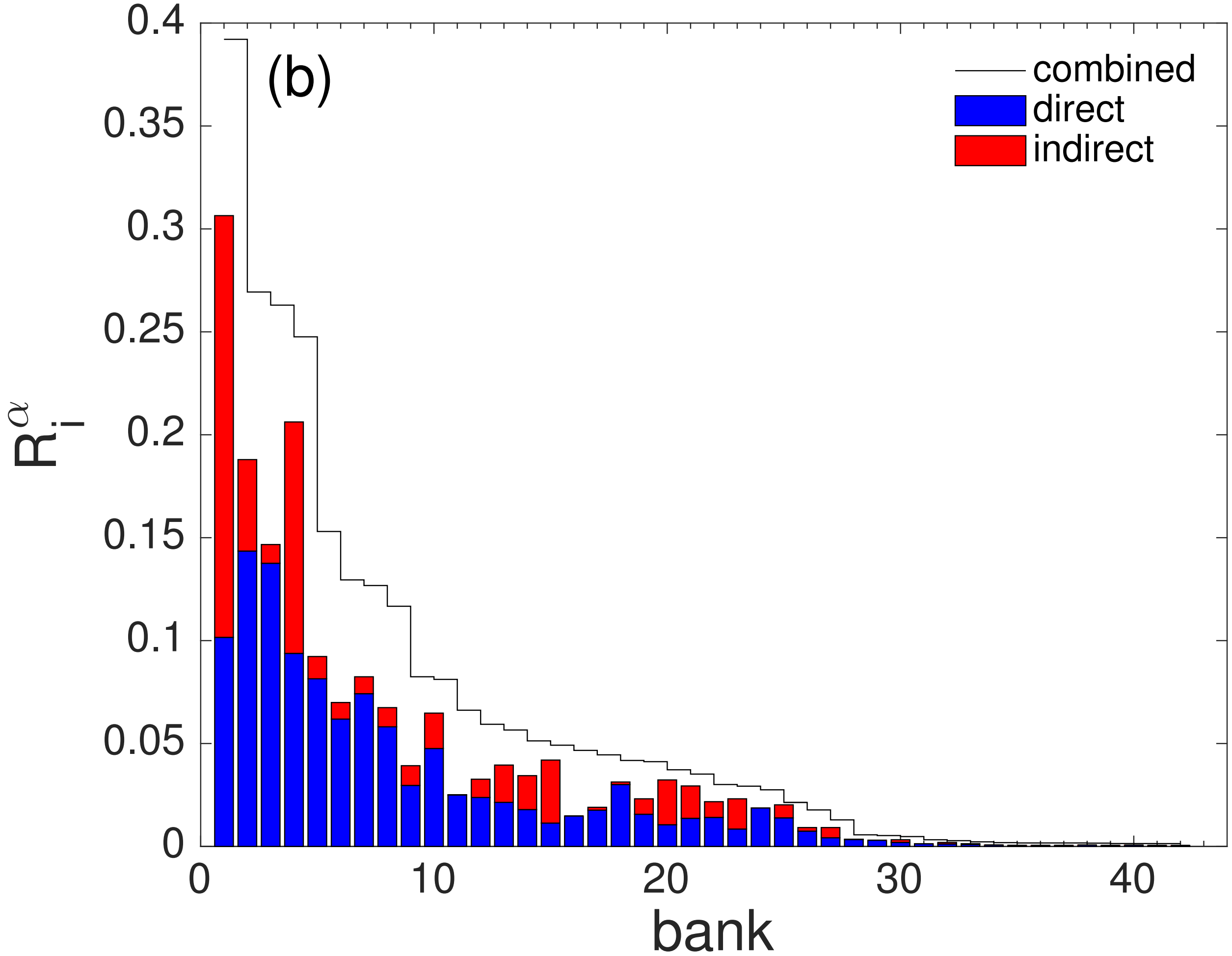
*with Serafín Martínez-Jaramillo and team at Banco de Mexico

Systemic risk profile from direct exposures

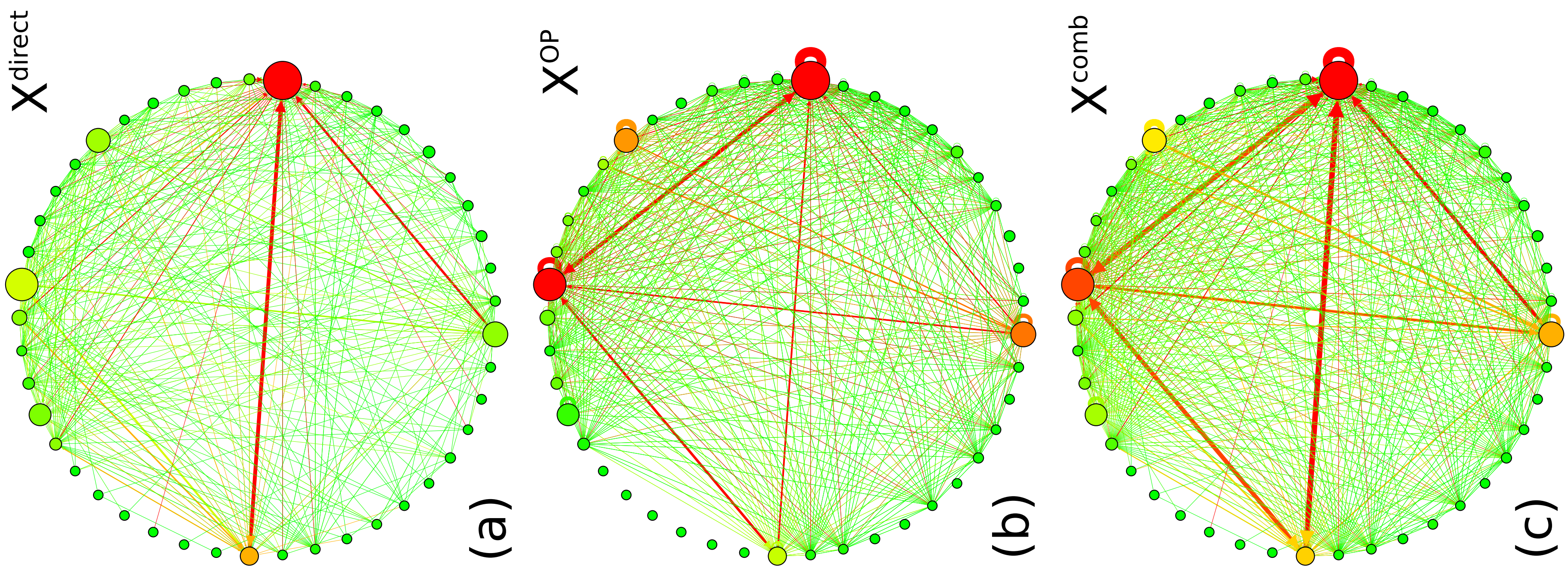


*with Serafín Martínez-Jaramillo and team at Banco de Mexico

Systemic risk profile from overlapping portfolios



Exposures from direct exposures and overlapping portfolios



total exposure overlapping pf $\sum_{i,j} X_{ij}^{\mathrm{OP}} \sim 1 \times 10^{12}$ Mex$

total direct exposures $\sum_{i,j} X_{ij}^{\mathrm{direct}} \sim 3.3 \times 10^{11}$ Mex$

How big is the next financial crisis?

Expected systemic loss [Euro / Year]

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

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

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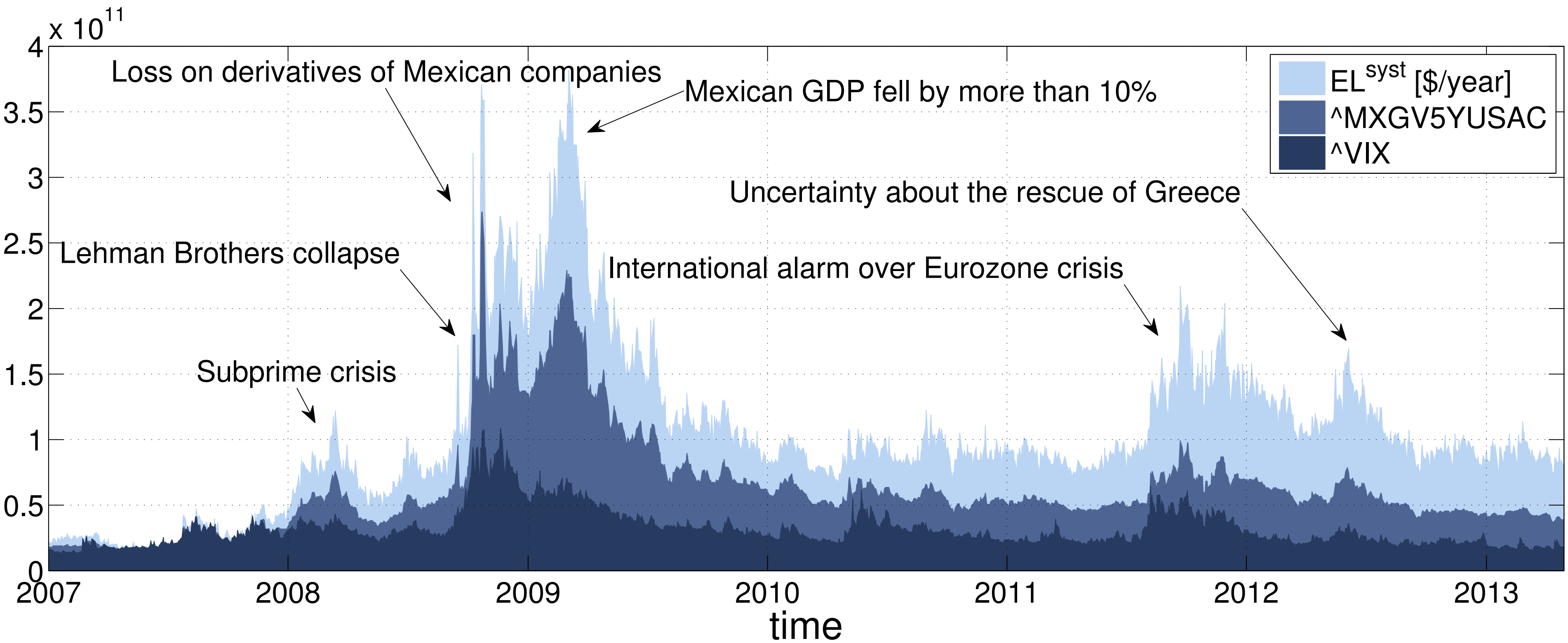
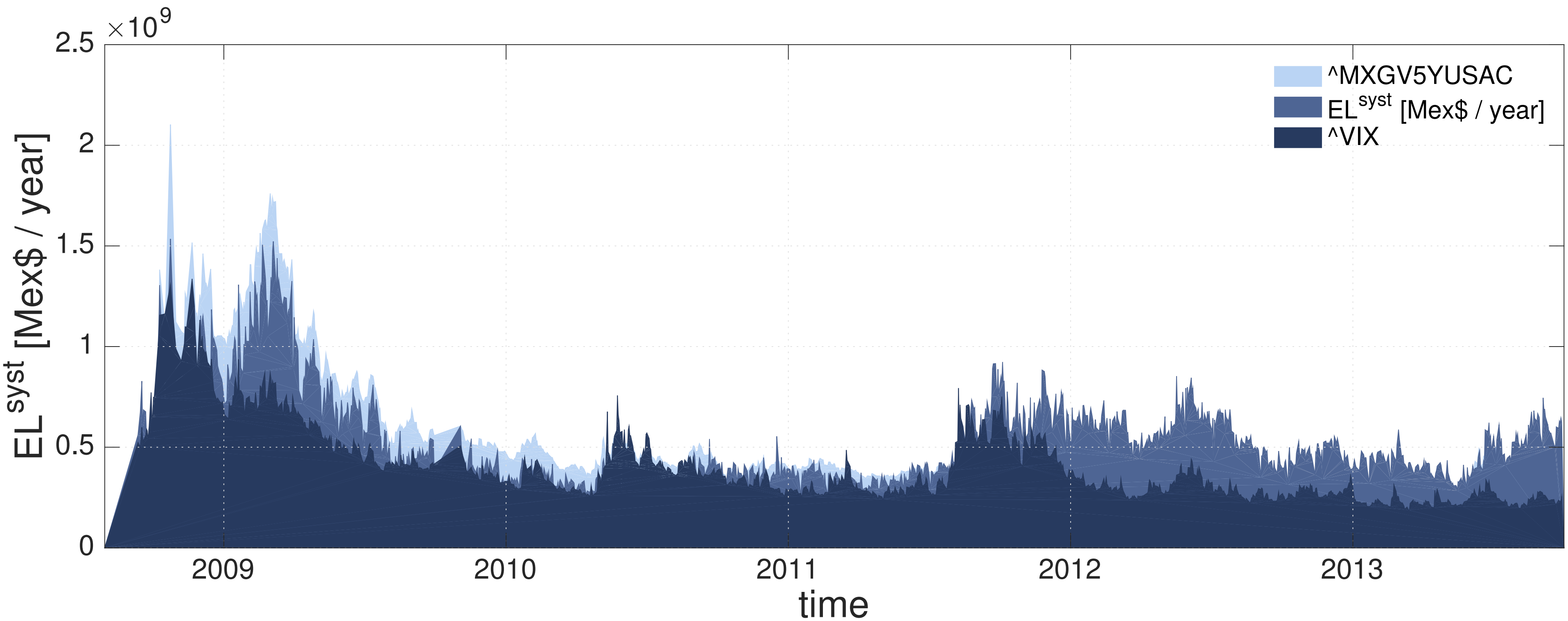
$$
\begin{aligned}
\mathrm{EL}^{\mathrm{syst}} &= V \sum_{S \in \mathcal{P}(B)} \prod_{i \in S} p_i \prod_{j \in B \setminus S} (1 - p_j)\,(R_S) \\
&\approx V \sum_{S \in \mathcal{P}(B)} \prod_{i \in S} p_i \prod_{j \in B \setminus S} (1 - p_j) \left(\sum_{i \in S} R_i \right) \\
&= V \sum_{i=1}^{b}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

Expected systemic loss index for Mexico*



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

Expected systemic loss from overlapping pfs



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?

- note: **importance to to details !!!**

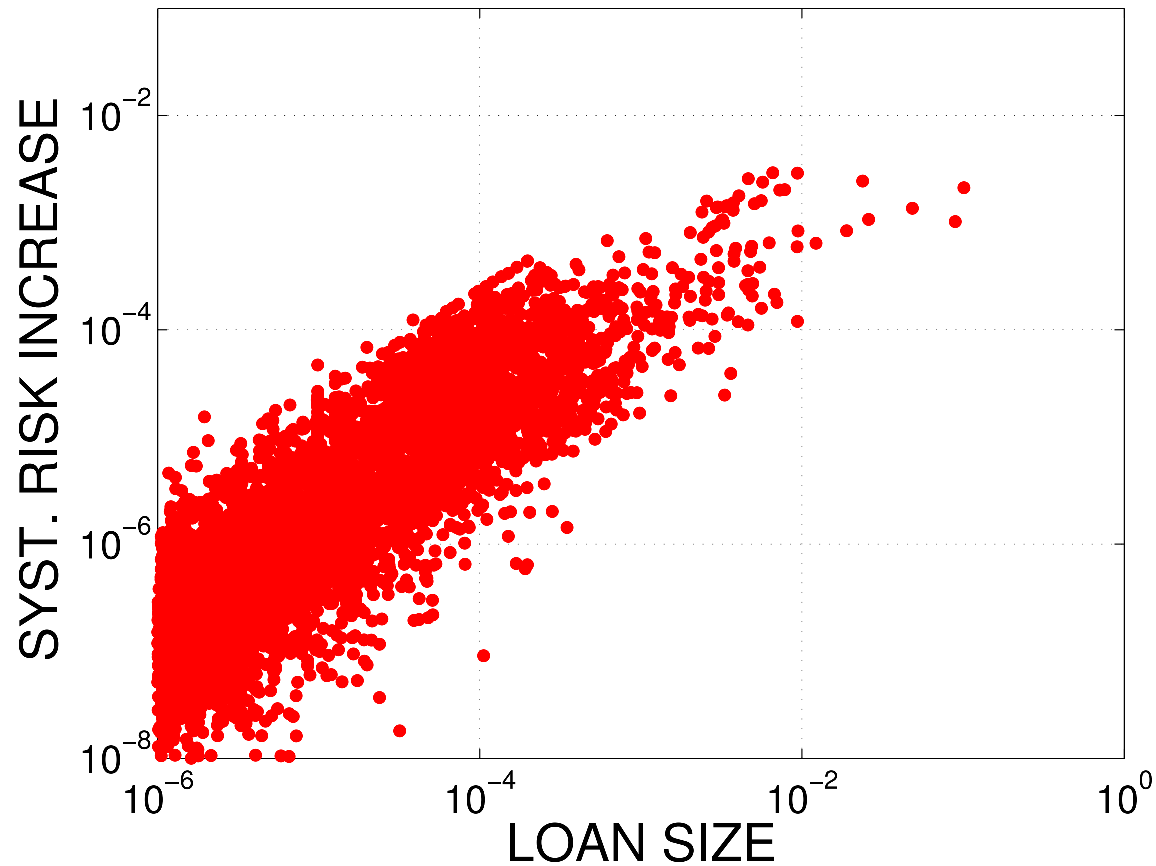
Observation

Systemic risk of a node changes with every transaction

Marginal expected systemic loss index

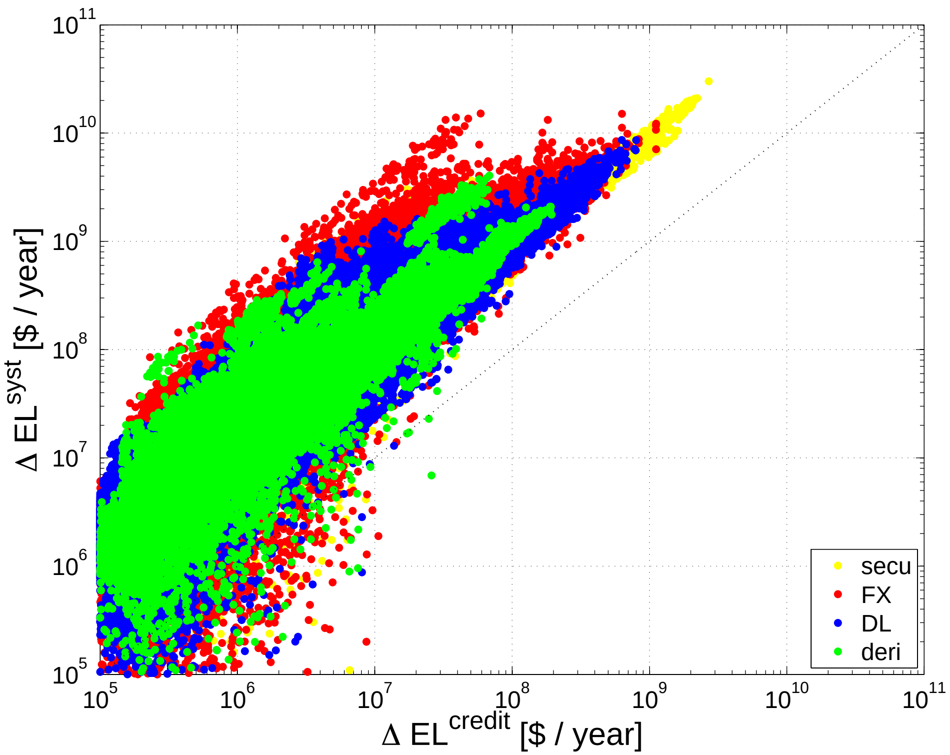
$$\Delta\mathrm{EL}^{\mathrm{syst}}(\Delta X_{kl}) = \sum_{i=1}^{B} p_i \left[V(X_{ij} + \Delta X_{kl})\, R_i(X_{ij} + \Delta X_{kl}, C_i) \;\; - V(X_{ij})\, R_i(X_{ij}, C_i)\right]$$

Austria all interbank loans



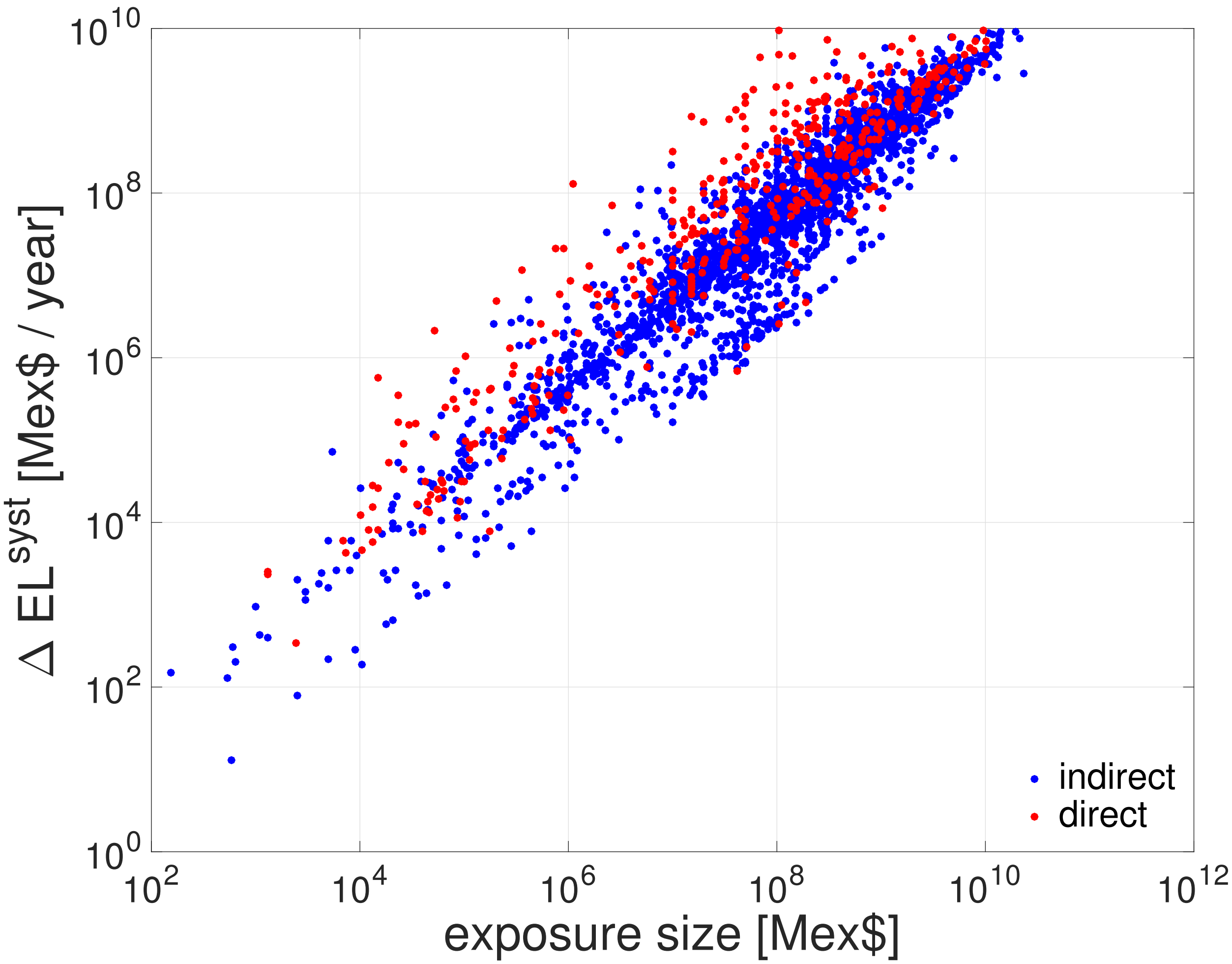
note orders of magnitude !

Mexican data



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

Marginal systemic risk from overlapping pfs



systemic risk is an externality

Management of systemic risk

- systemic risk is a network property

$\rightarrow$ manage systemic risk: **re-structure financial networks** such that cascading failure becomes unlikely / impossible systemic risk management

=

re-structure networks

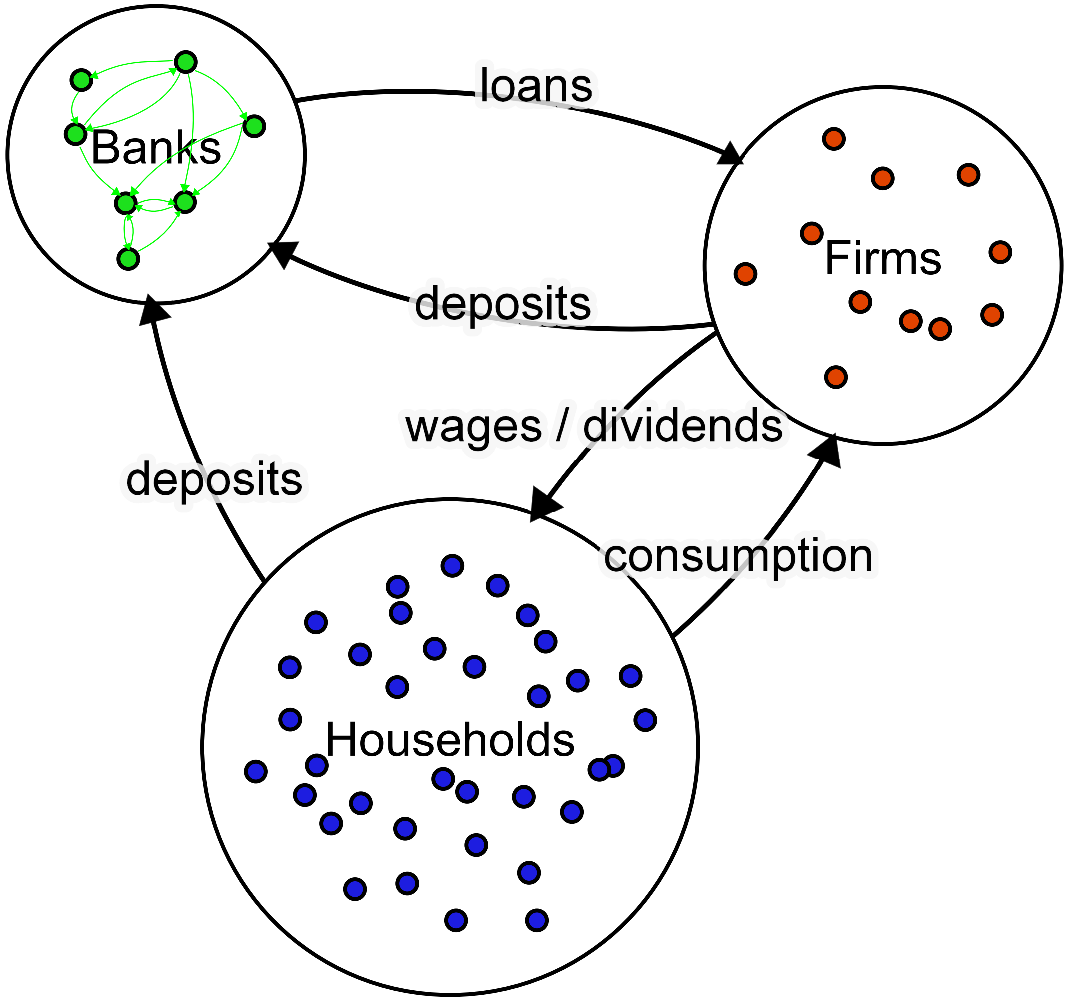
Systemic risk elimination

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

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

- size of tax $\propto$ expected systemic loss of transaction

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



The agents

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

$\rightarrow$ 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^{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^{h}), and among other firms (consumption)

For comparison: implement Tobin-like tax

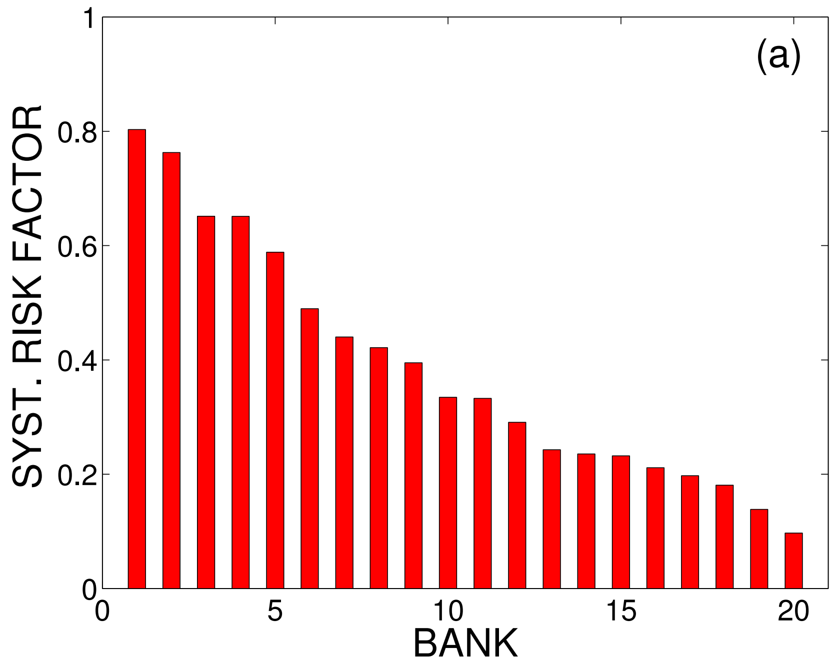
- tax all transactions regardless of their risk contribution
- 0.2% of transaction ($\sim$ 5% of interest rate)

Comparison of three schemes

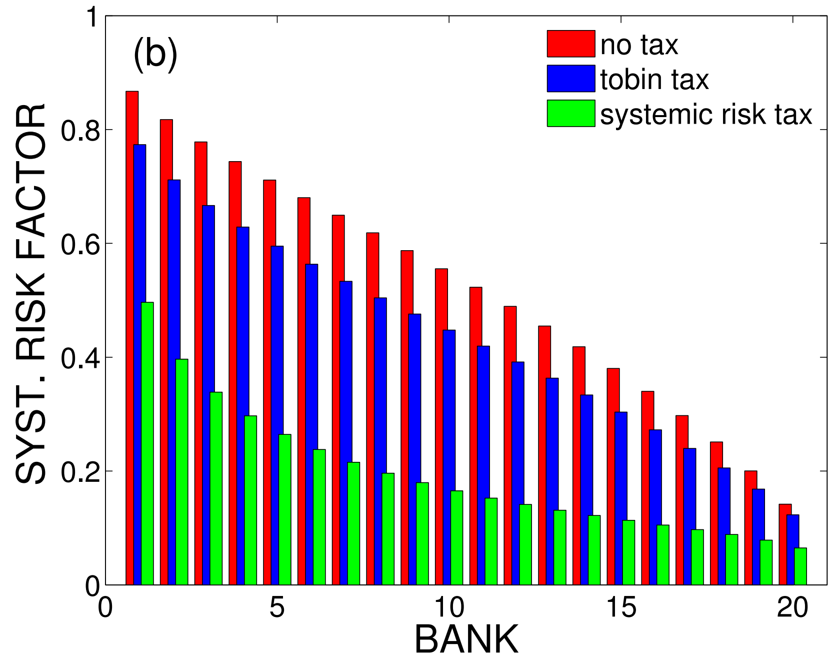
- No systemic risk management
- Systemic Risk Tax (SRT)
- Tobin-like tax

Model results: Systemic risk profile

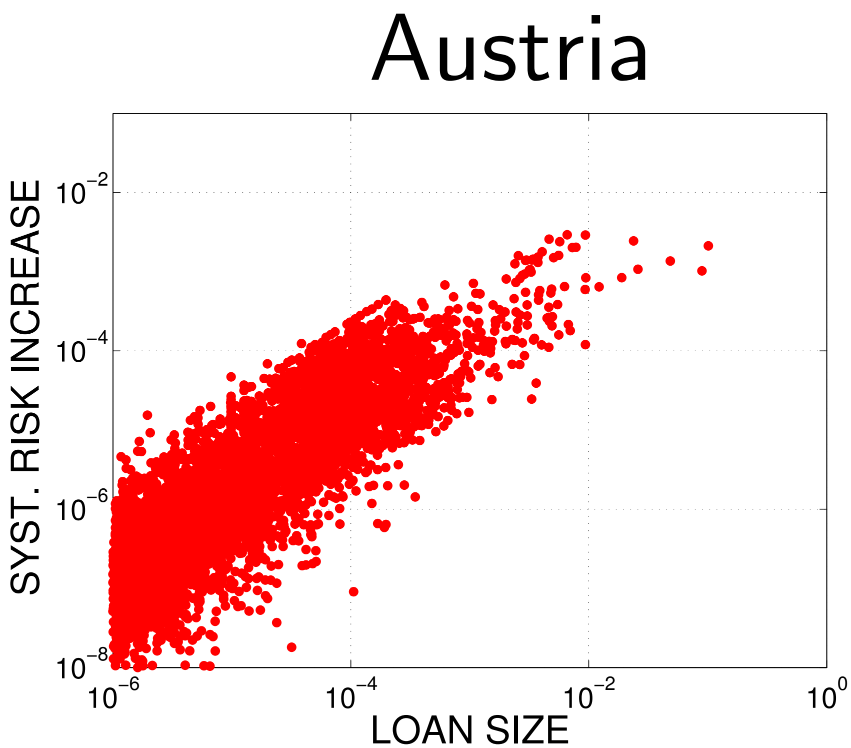
Austria

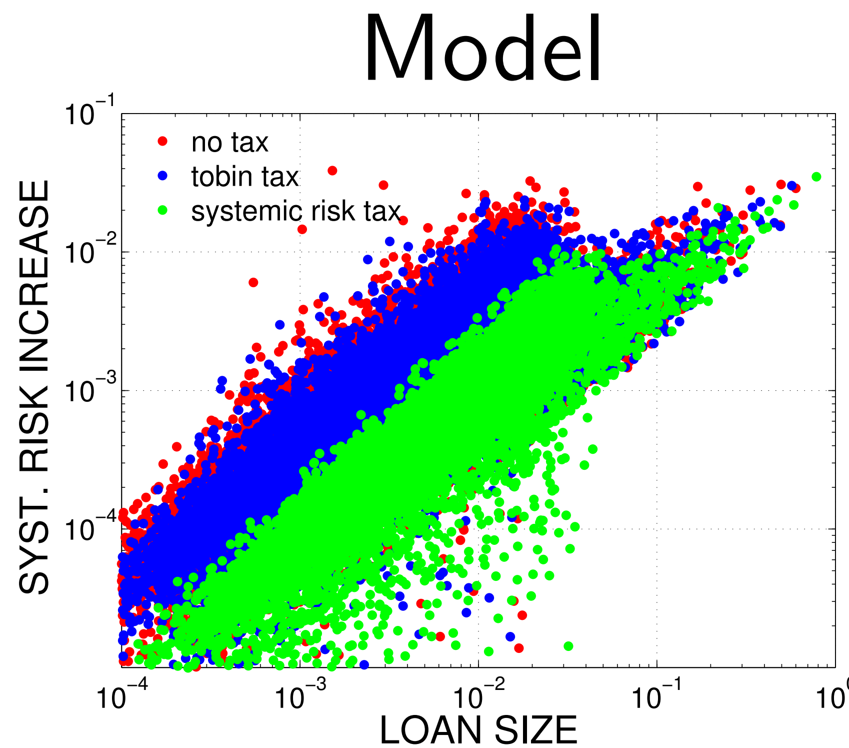


Model

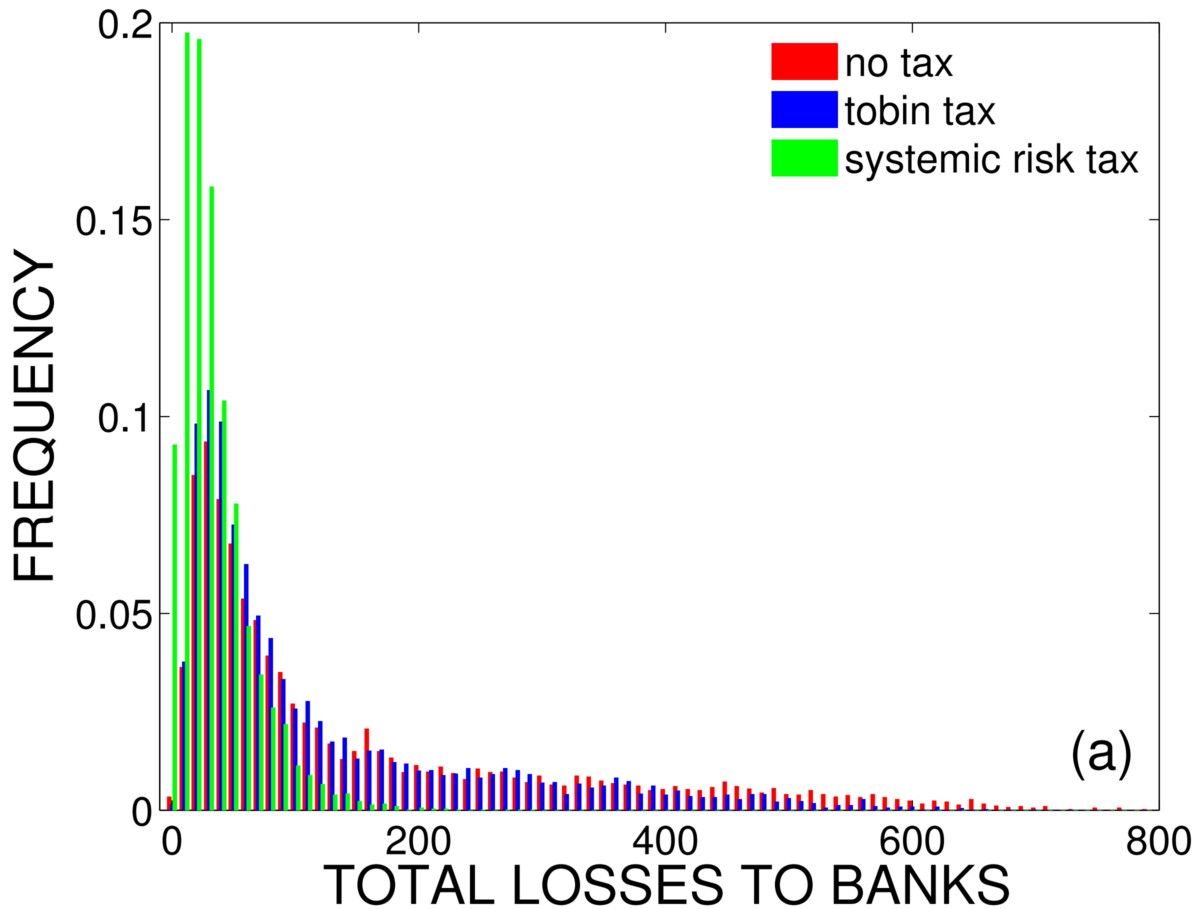


Model results: Systemic risk of individual loans



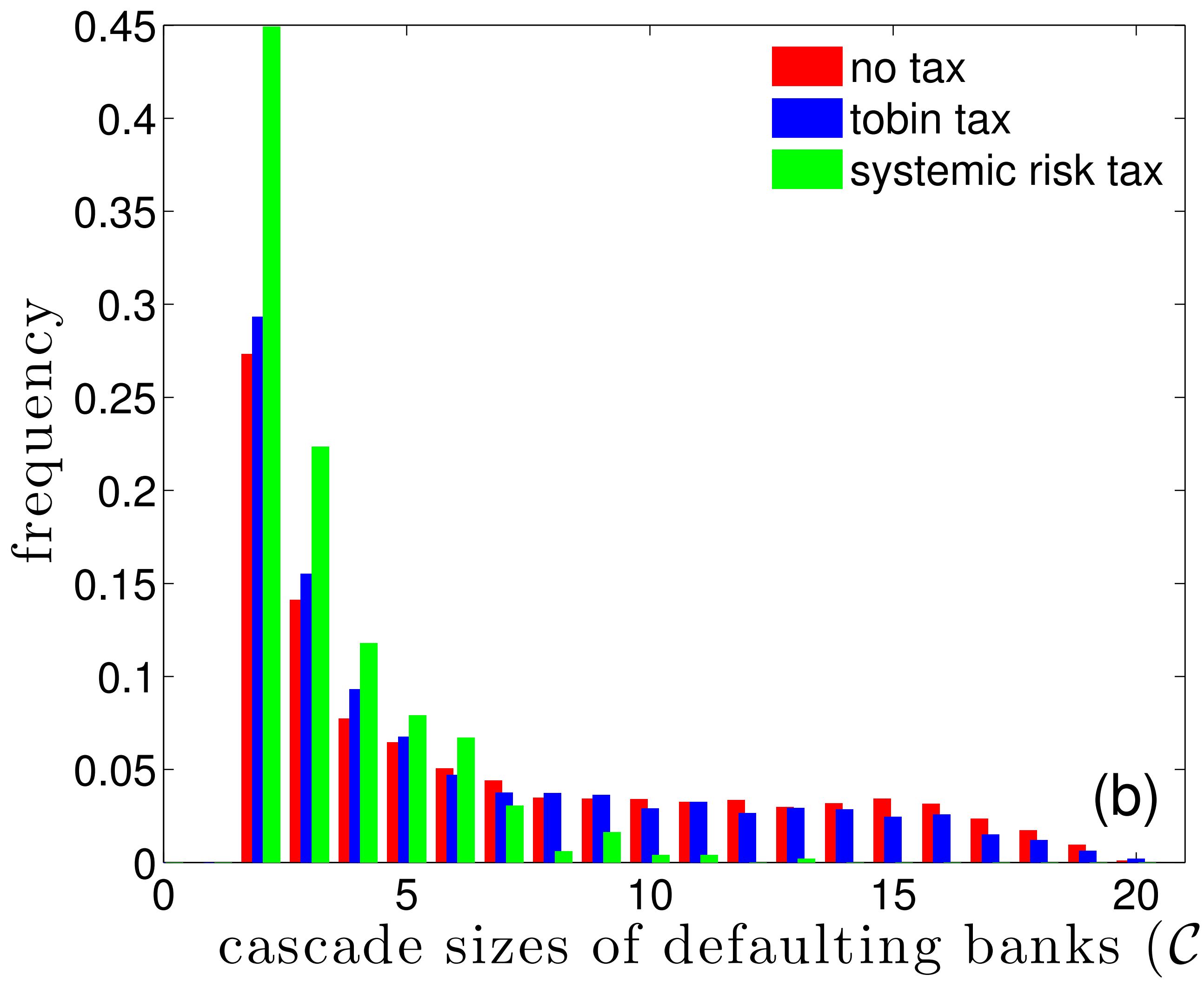


Model results: Distribution of losses

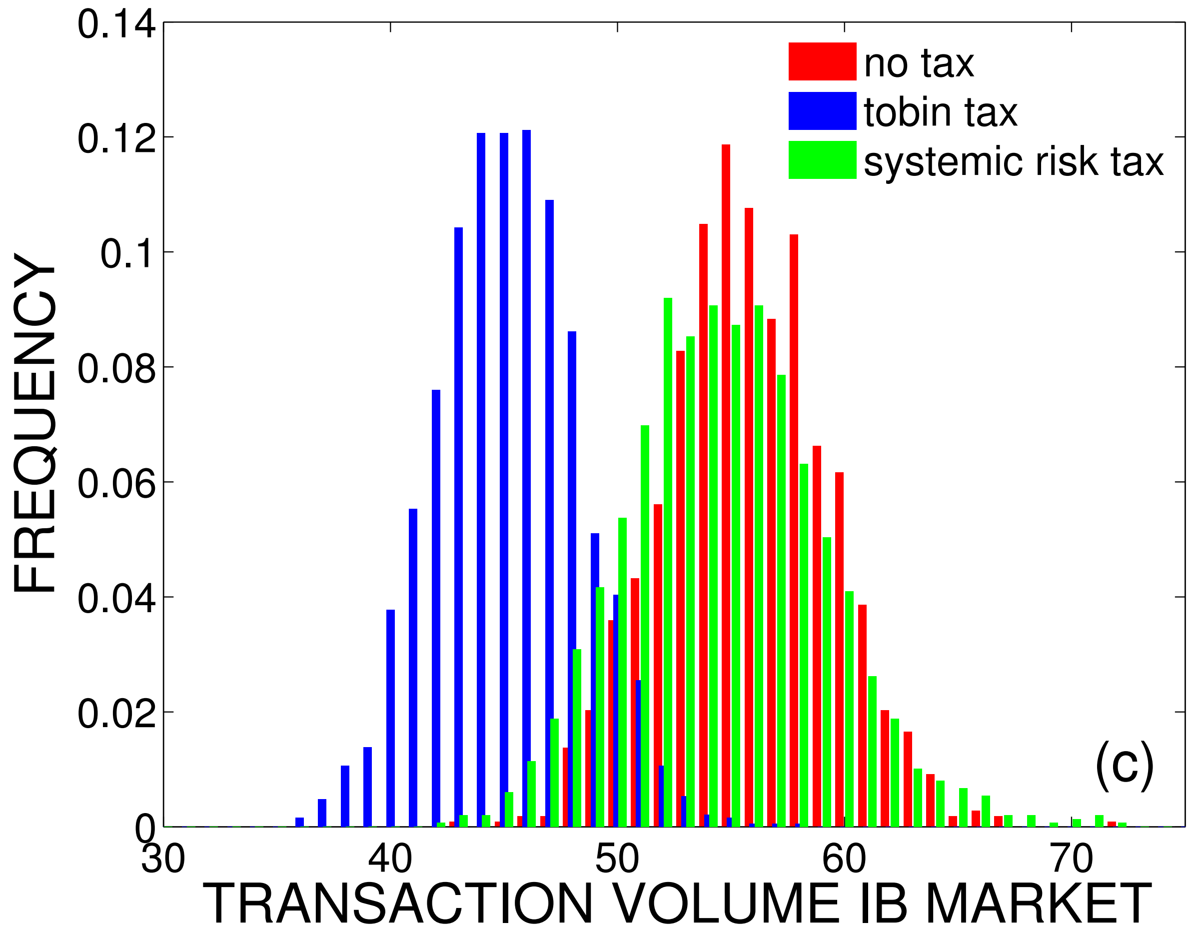


SRT eliminates systemic risk. How?

Model results: Cascading is suppressed



Model results: Credit volume



Tobin tax reduces risk by reducing credit volume

Mathematical proof:

SR-free equilibrium under SRT exists

M. Leduc, S. Thurner, J Economic Dynamics and Control 82 (2017) 44

Reduce SR from overlapping portfolios?

$\rightarrow$ see talk of Anton Pichler

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M. Leduc, S. Thurner

J Economic Dynamics and Control 82 (2017) 44

Conclusions

- systemic risk is a network property – endogenously created
- can be measured for each institution / transaction
- 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 multi-layer network framework
- SR tax is technically feasible
- SR can be drastically reduced as a optimization problem