Elimination of systemic risk in financial markets

Stefan Thurner

www.complex-systems.meduniwien.ac.at www.santafe.edu

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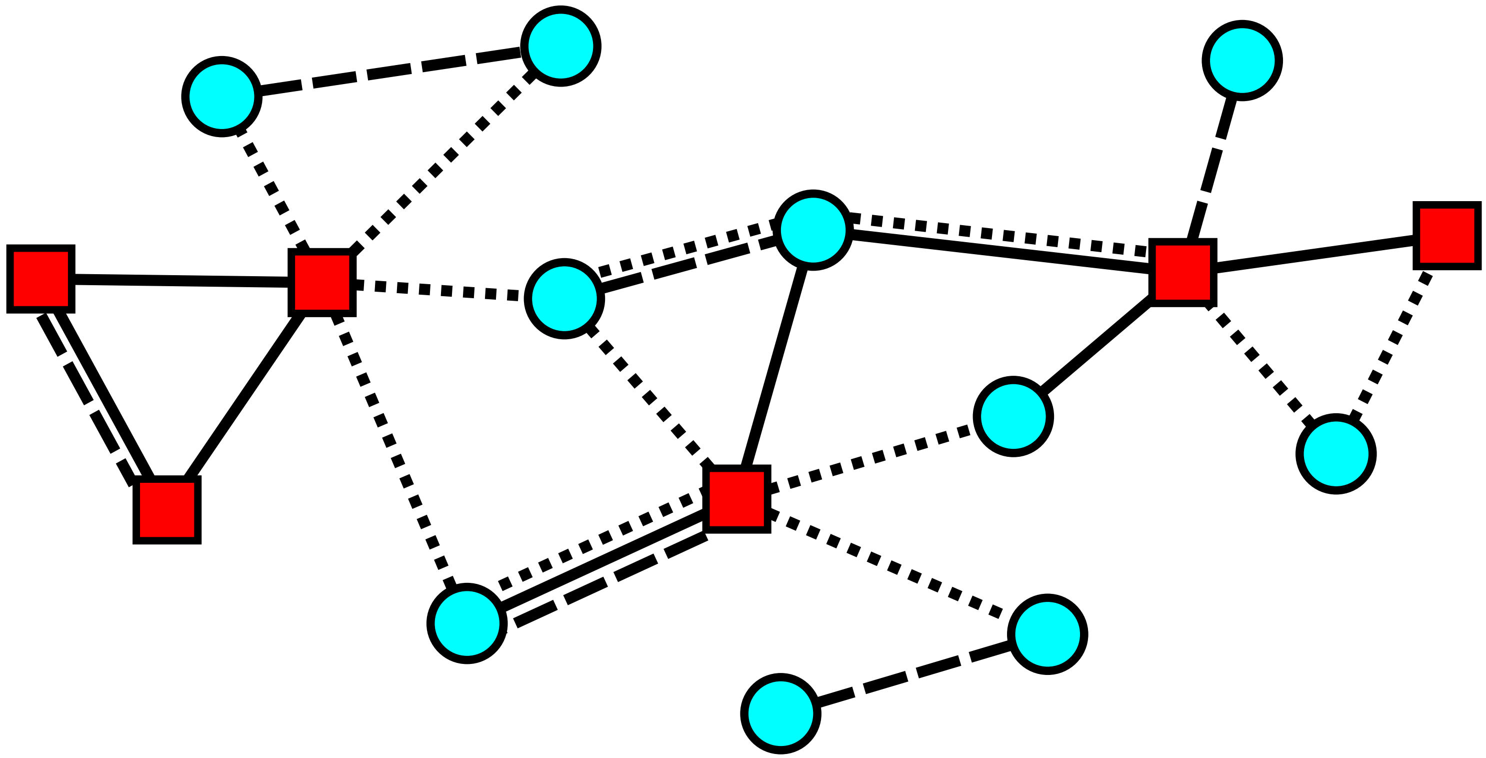
Collaborators

Sebastian Poledna
Peter Klimek
Serafin Martinez-Jamarillo
Jose-Luis Molina Balboa
Marco van der Leij
Abraham Hinteregger



- nodes i characterized by states, $\sigma_i^\beta(t)$
- links multiplex network, $M_{ij}^\alpha(t)$

Complex system=co-evolving multiplex network

$$\frac{d}{dt}\sigma_i^\alpha(t) \sim F\left(M_{ij}^\alpha(t), \sigma_j^\beta(t)\right)$$

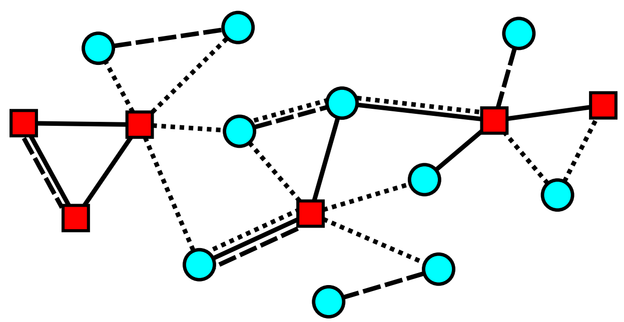
and

$$\frac{d}{dt}M_{ij}^\alpha(t) \sim G\left(M_{ij}^\alpha(t), \sigma_j^\beta(t)\right)$$

- states are observable (big data)
- networks are observable (big data)
- context is there

Complex system=co-evolving multiplex network

- algorithmic
- path dependent
- context dependent
- open-ended
- adaptive
- cascading dynamics



Complex systems are intrinsically instable

complex systems are intrinsically stochastic

statistics of complex systems is the **statistics of power laws**

- large number of large outliers – outliers are normal

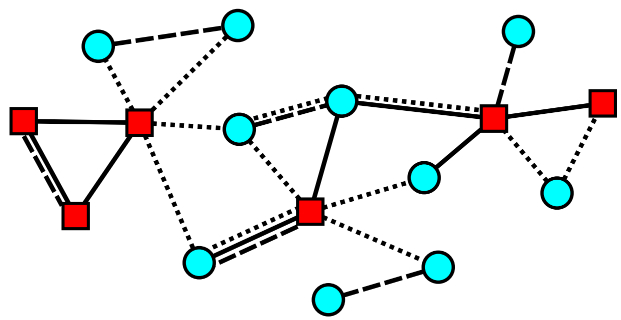
→ non-managable

Can we control systemic risk?

given we know all details

The three types of financial risk

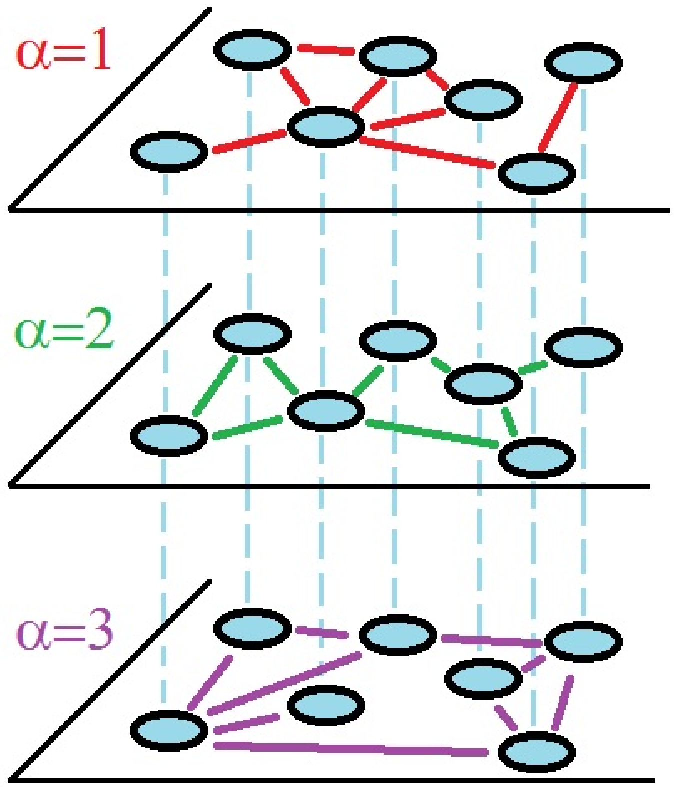
- **economic risk:** investment in business idea does not pay off
- **credit-default risk:** you don't get back what you have lent
- **systemic risk:** system stops functioning due to local defaults and subsequent cascading (massive restructuring of links)



The 2 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 multi-layer networks



layer 1: lending–borrowing loans

layer 2: derivative networks

layer 3: collateral networks

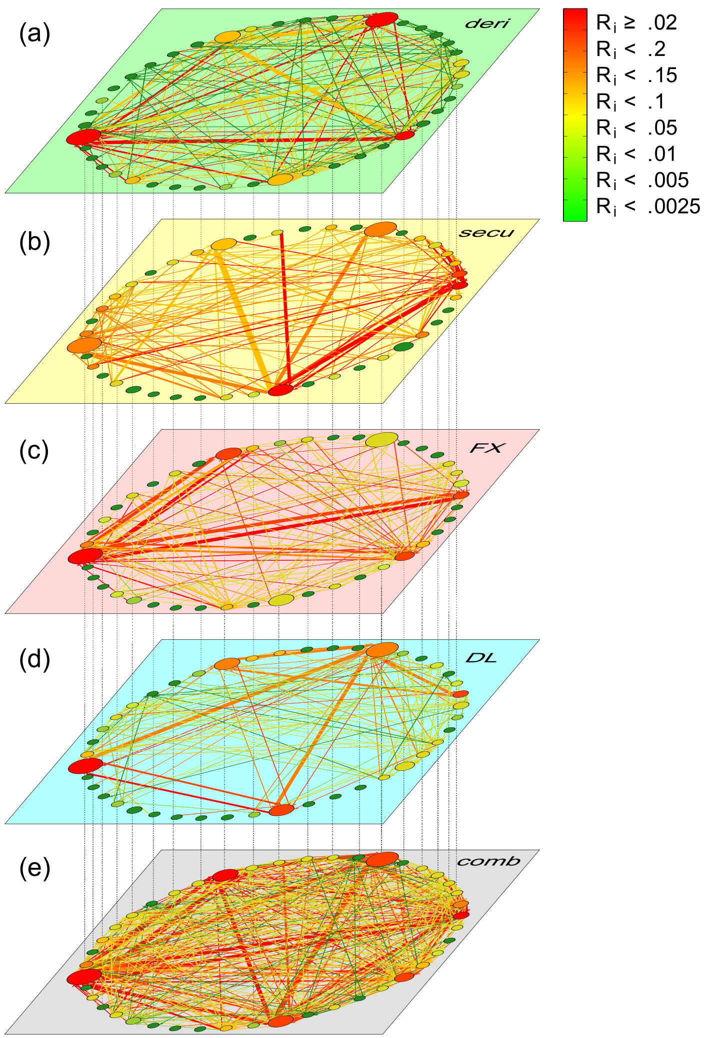
layer 4: securities networks

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
$R_i \geq .02$
$R_i < .2$
$R_i < .15$
$R_i < .1$
$R_i < .05$
$R_i < .01$
$R_i < .005$
$R_i < .0025$

Quantification of SR

Systemic risk – quantification

Wanted: systemic risk-value for every financial institution

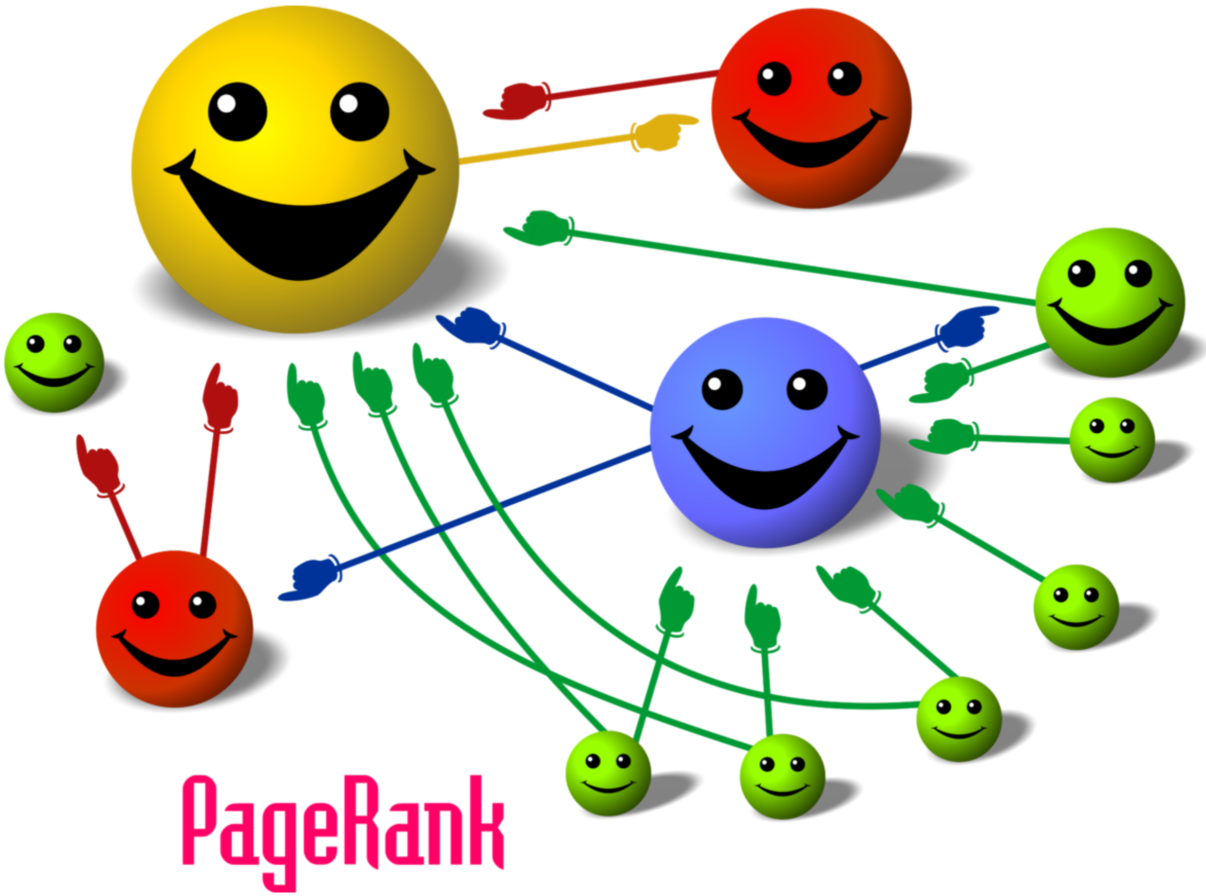
given: transaction network + capitalization

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

→ page is important if many important pages point to it

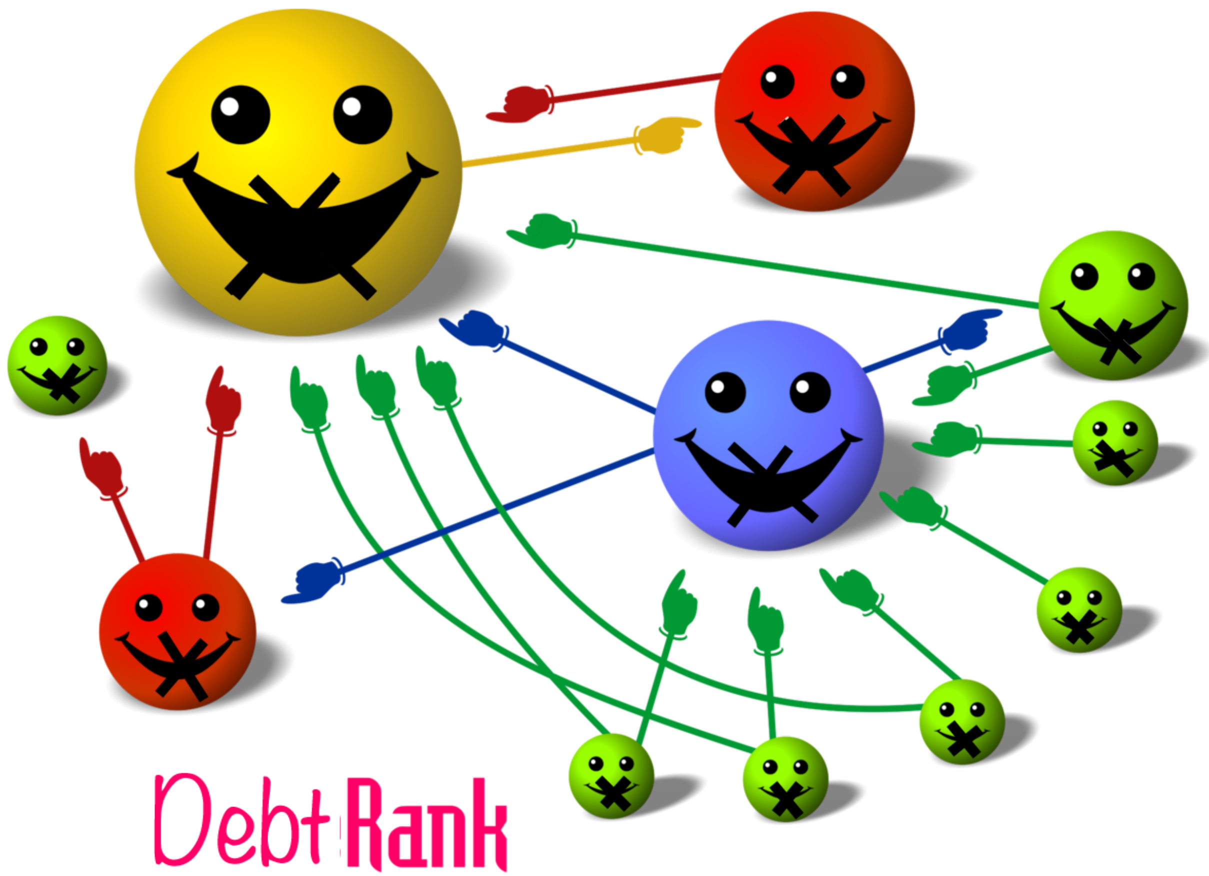
→ number for importance → PageRank

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?

- **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

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

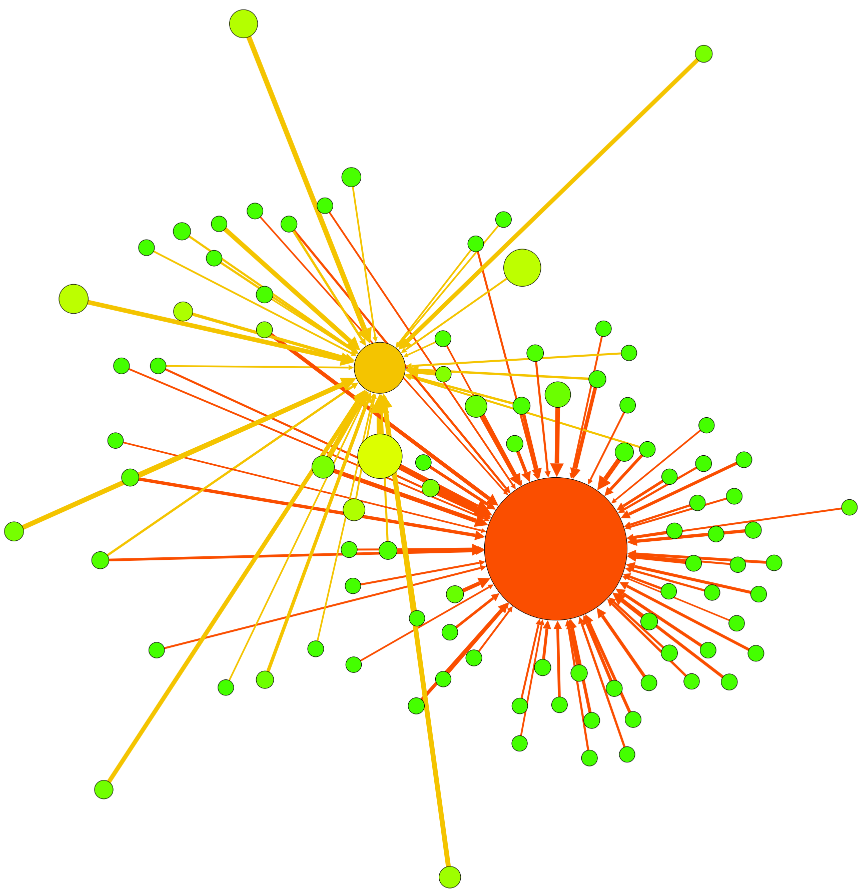
Systemic risk of nodes

Input: Network of contracts between banks

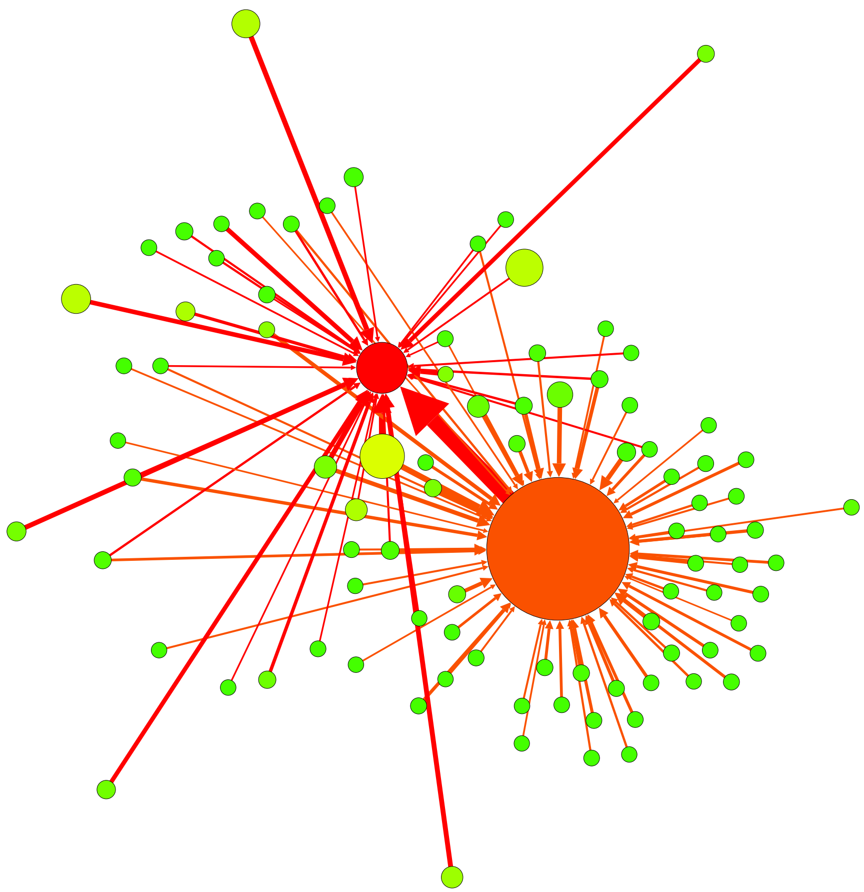
Compute = DebtRank; think of a complicated first eigenvector

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

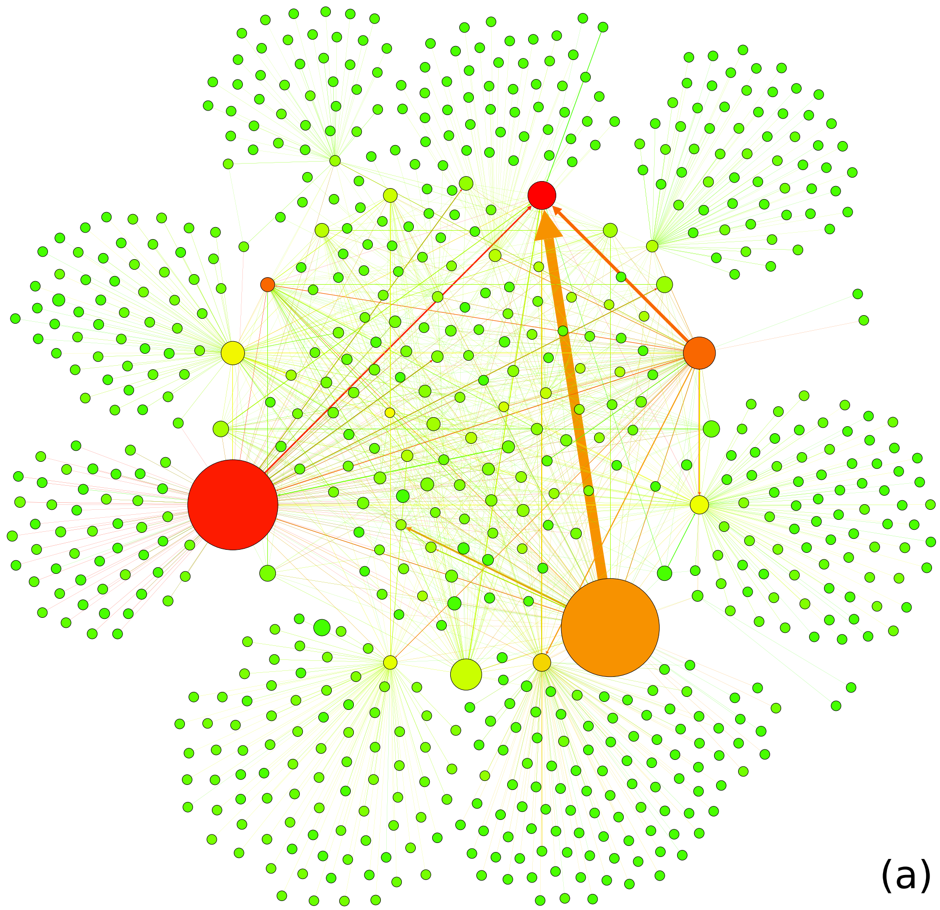
Systemic risk spreads by borrowing



Systemic risk spreads by borrowing



DebtRank Austria Sept 2009

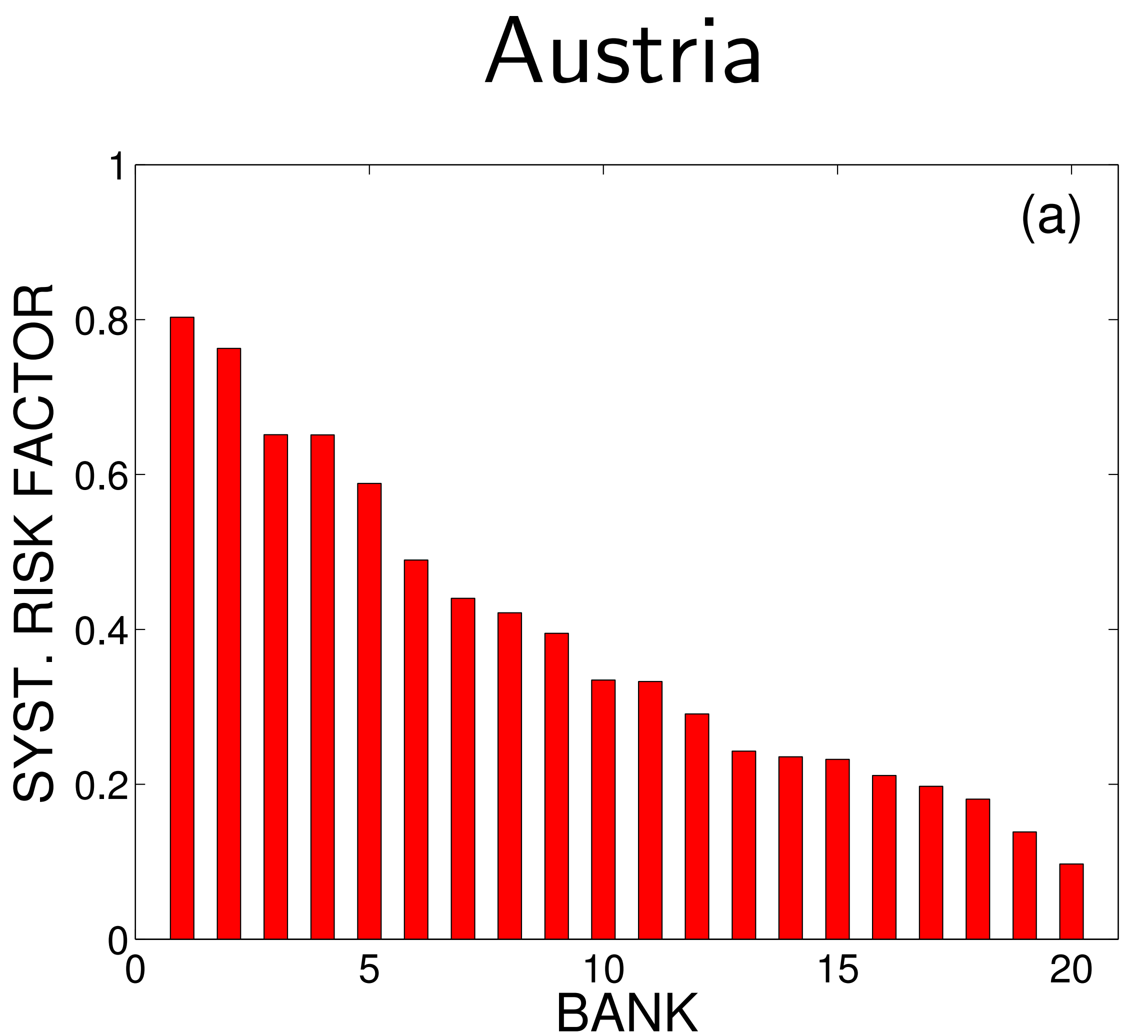


(a)

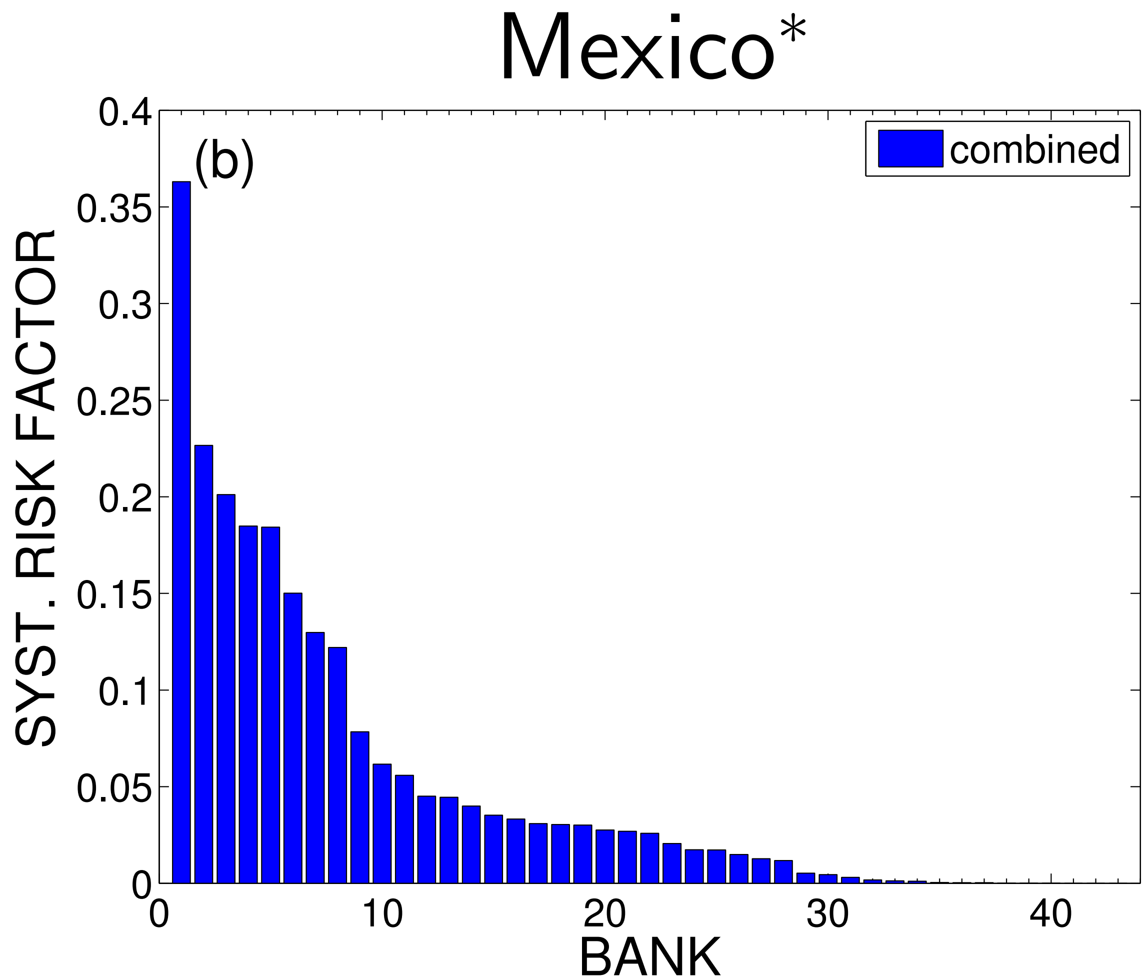
note: size is not proportional to systemic risk

note: core-periphery structure

Systemic risk profile



Systemic risk profile



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

How big is the next financial crisis?

Expected systemic loss [Euro / Year]

ESL $= \sum_i p_{\mathrm{default}}(\mathsf{i})\ .\ \mathsf{DebtRank}(\mathsf{i})$

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

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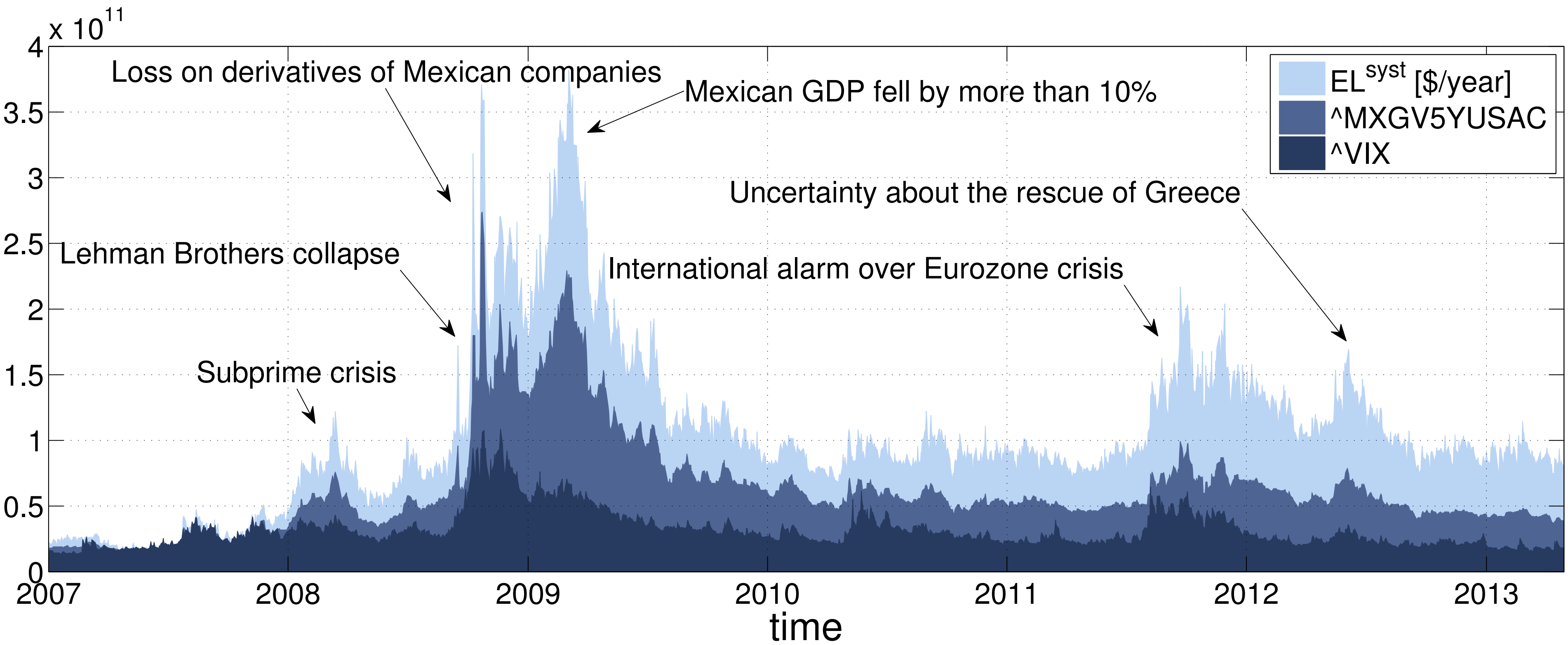
Expected systemic loss index for Mexico*

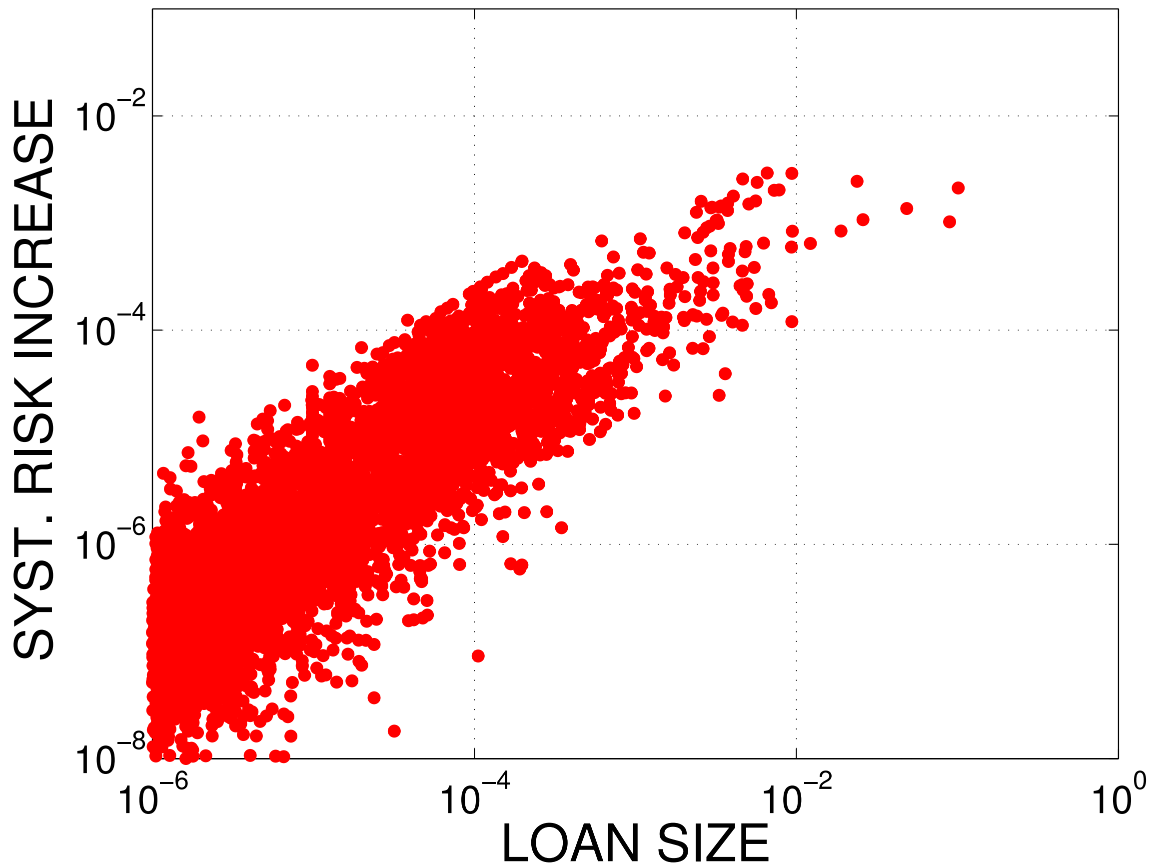


*with Serafin Martinez-Jaramillo and team at Banco de Mexico, 2014

Observation

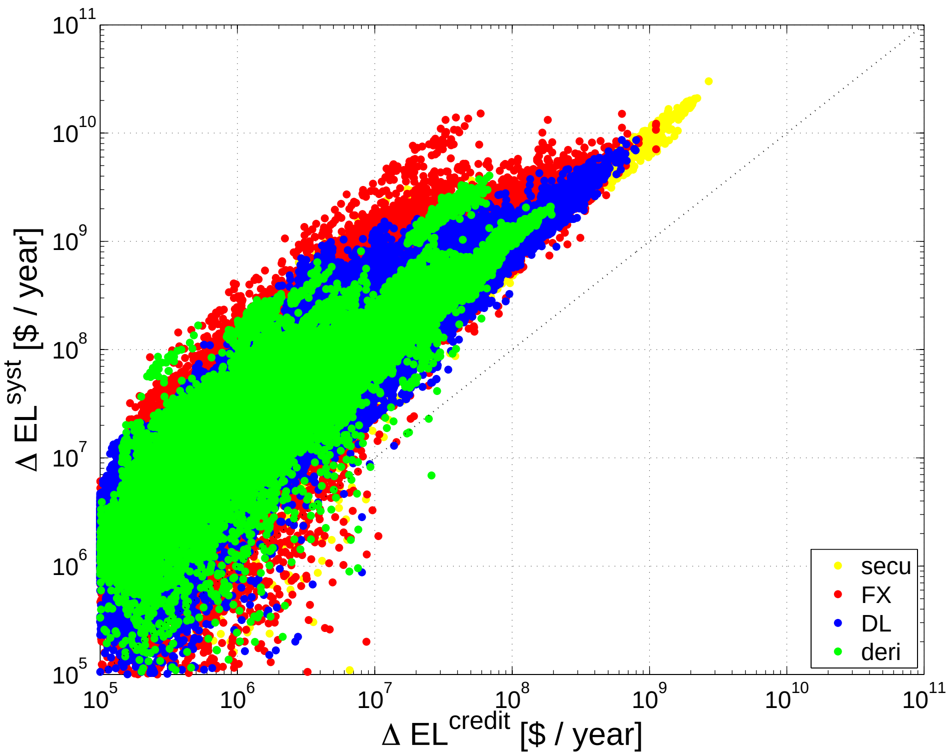
Systemic risk of a node changes with every transaction

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

→ 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? → increase of expected syst. loss
- ergo: restrict transactions with high systemic risk

→ **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 MUST not be reduced 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

Mathematical proof:

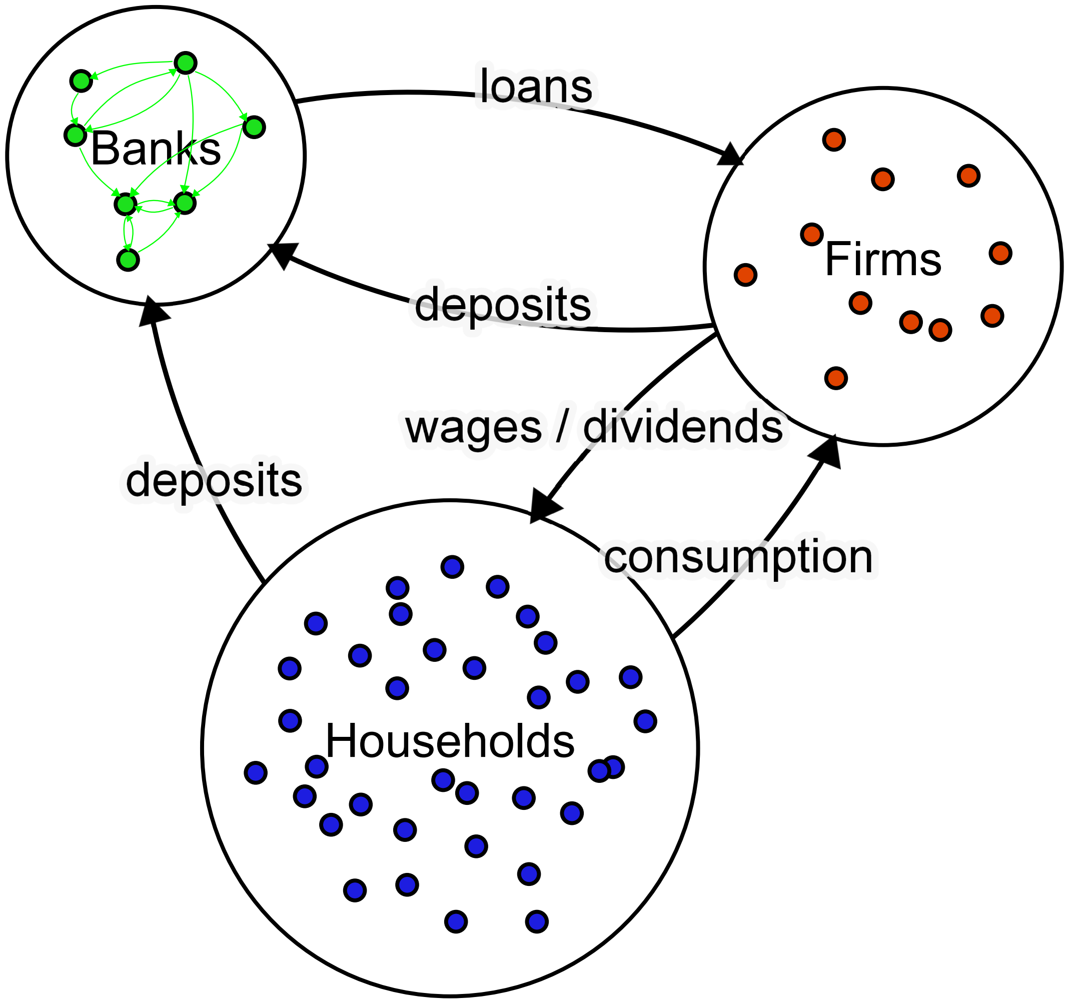
SR-free equilibrium under SRT exists

Proposition *Systemic Risk under Systemic Risk Tax.*
Let $(\mathcal{B}_t, \mathcal{L}_t, \mathbf{P})$ be a market for liquidity at time t. Given a net exposure matrix $\bar{A}_{t-1}$ at time $t-1$, let $\bar{A}_t^{*,\mathcal{T}}$, $\bar{A}_t^{*,\kappa}$ and $\bar{A}_t^*$ be the net exposure matrices formed at time t with a SRT $\mathcal{T}$, with a Tobin-like tax κ and without tax by the equilibrium matchings $\mu_t^{*,\mathcal{T}}$, $\mu_t^{*,\kappa}$ and μ_t^*, respectively. Then,

- (i) for any $\mu_t^* \in \mathcal{EQ}_t$, such that $Vol(\mu_t^*) = \nu$, there exists $\mathcal{T}$ such that $ESL(\bar{A}_t^{*,\mathcal{T}}, \vec{E}_t) \leq ESL(\bar{A}_t^*, \vec{E}_t)$ and $Vol(\mu_t^{*,\mathcal{T}}) \geq Vol(\mu_t^*)$; In particular, there exists $\mathcal{T}$ such that $\mu_t^{*,\mathcal{T}}$ is systemic risk efficient.

- (ii) for any $\mu_t^{*,\kappa} \in \mathcal{EQ}_t^\kappa$, such that $Vol(\mu_t^{*,\kappa}) = \nu$, there exists $\mathcal{T}$ such that $ESL(\bar{A}_t^{*,\mathcal{T}}, \vec{E}_t) \leq ESL(\bar{A}_t^{*,k}, \vec{E}_t)$ and $Vol(\mu_t^{*,\mathcal{T}}) \geq Vol(\mu_t^{*,k})$.

To see efficacy of tax: agent-based-model



The agents

- **firms:** ask bank for loans: random size, maturity τ, $r^{\mathrm{f-loan}}$
→ firms sell products to households: realise profit/loss
→ if surplus → deposit it bank accounts, for $r^{\mathrm{f-deposit}}$
→ firms are bankrupt if insolvent, or capital is below threshold
→ if firm is bankrupt, bank writes off outstanding loans

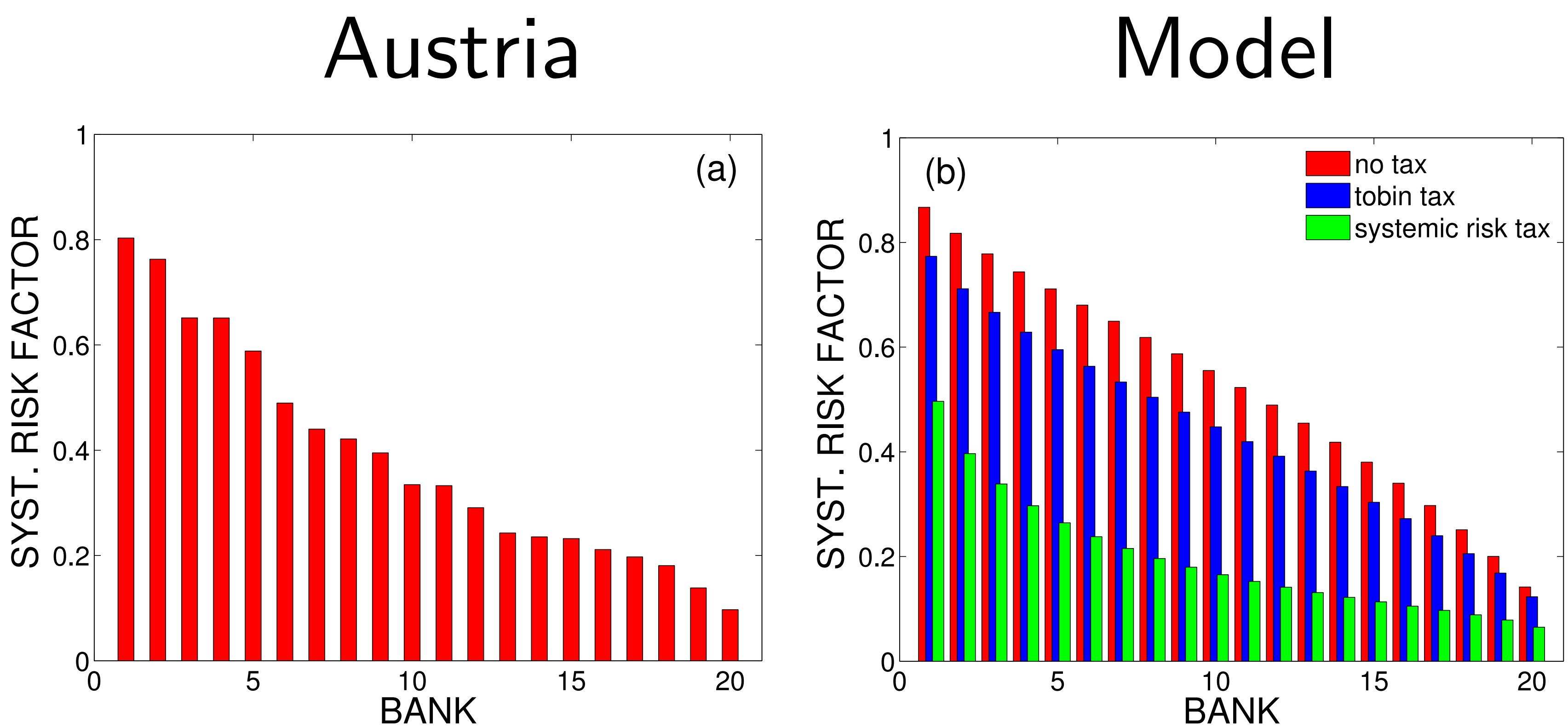
- **banks** try to provide firm-loans. If they do not have enough
→ approach other banks for interbank loan at interest rate r^{ib}
→ bankrupt if insolvent or equity capital below zero
→ bankruptcy may trigger other bank defaults

- **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)

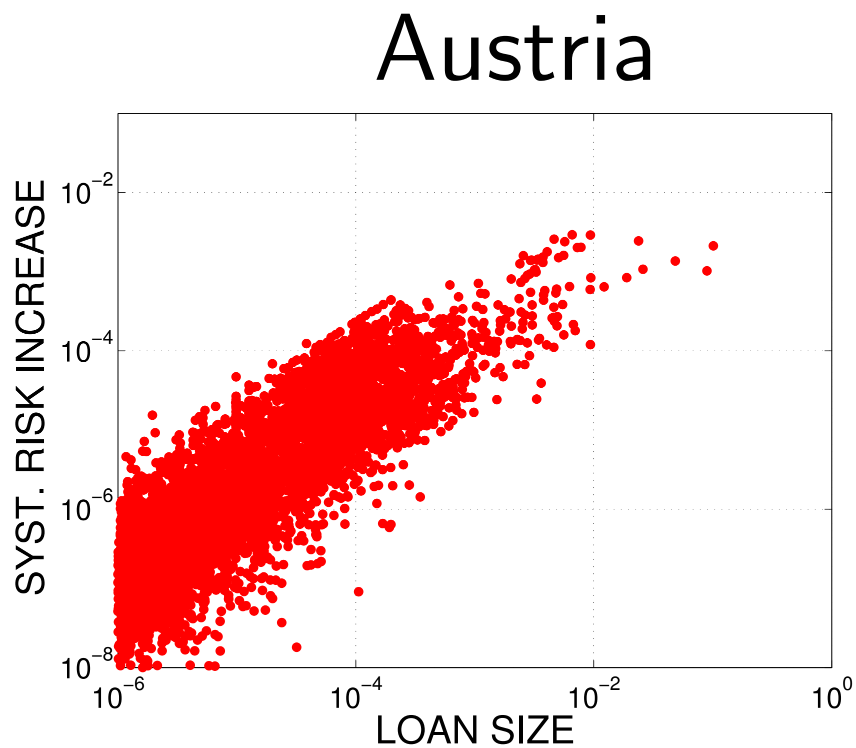
For comparison: implement Tobin-like tax

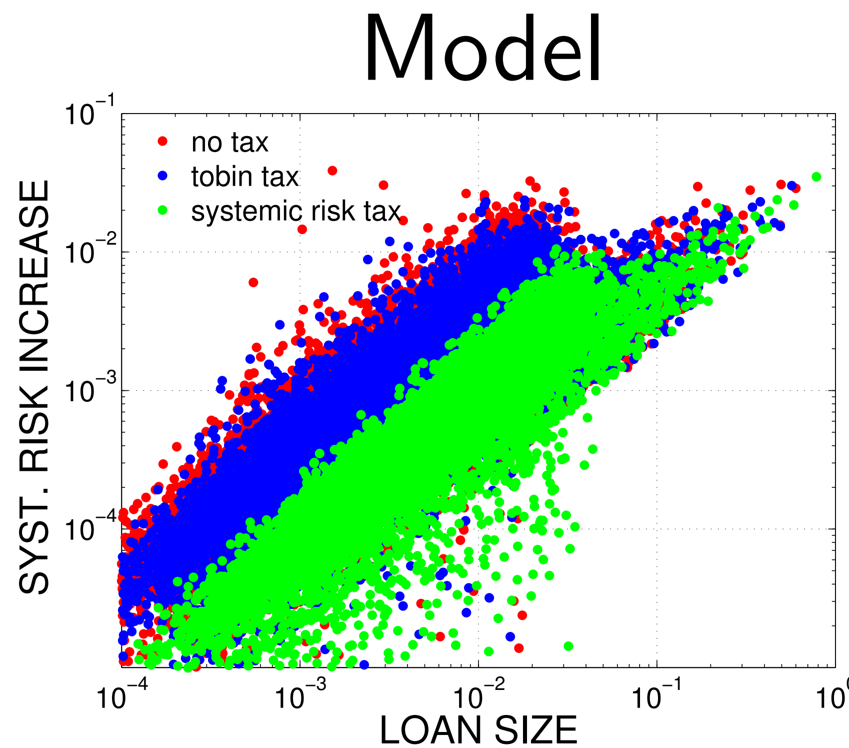
- tax all transactions regardless of their risk contribution
- 0.2% of transaction ($\sim$ 5% of interest rate)

Model results: systemic risk profile

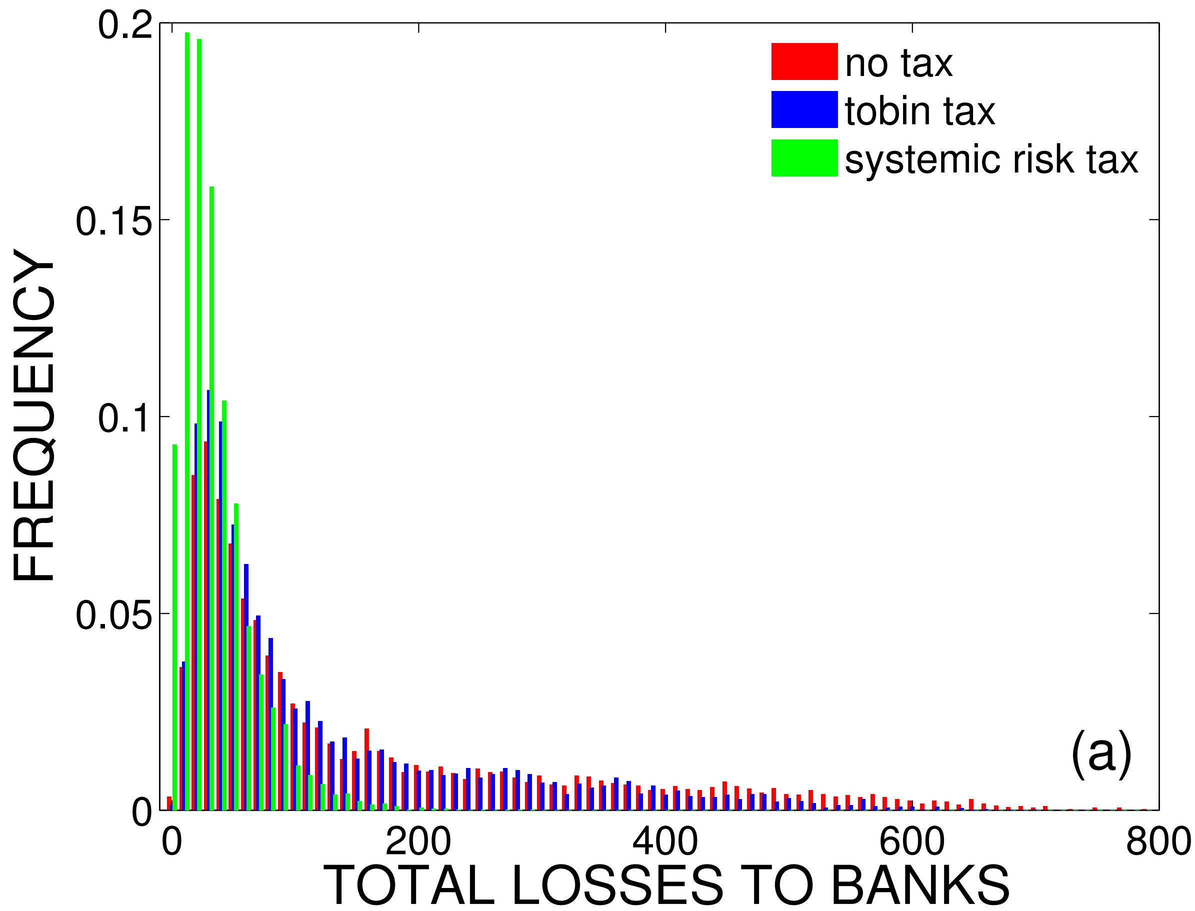


Model results: systemic risk of individual loans



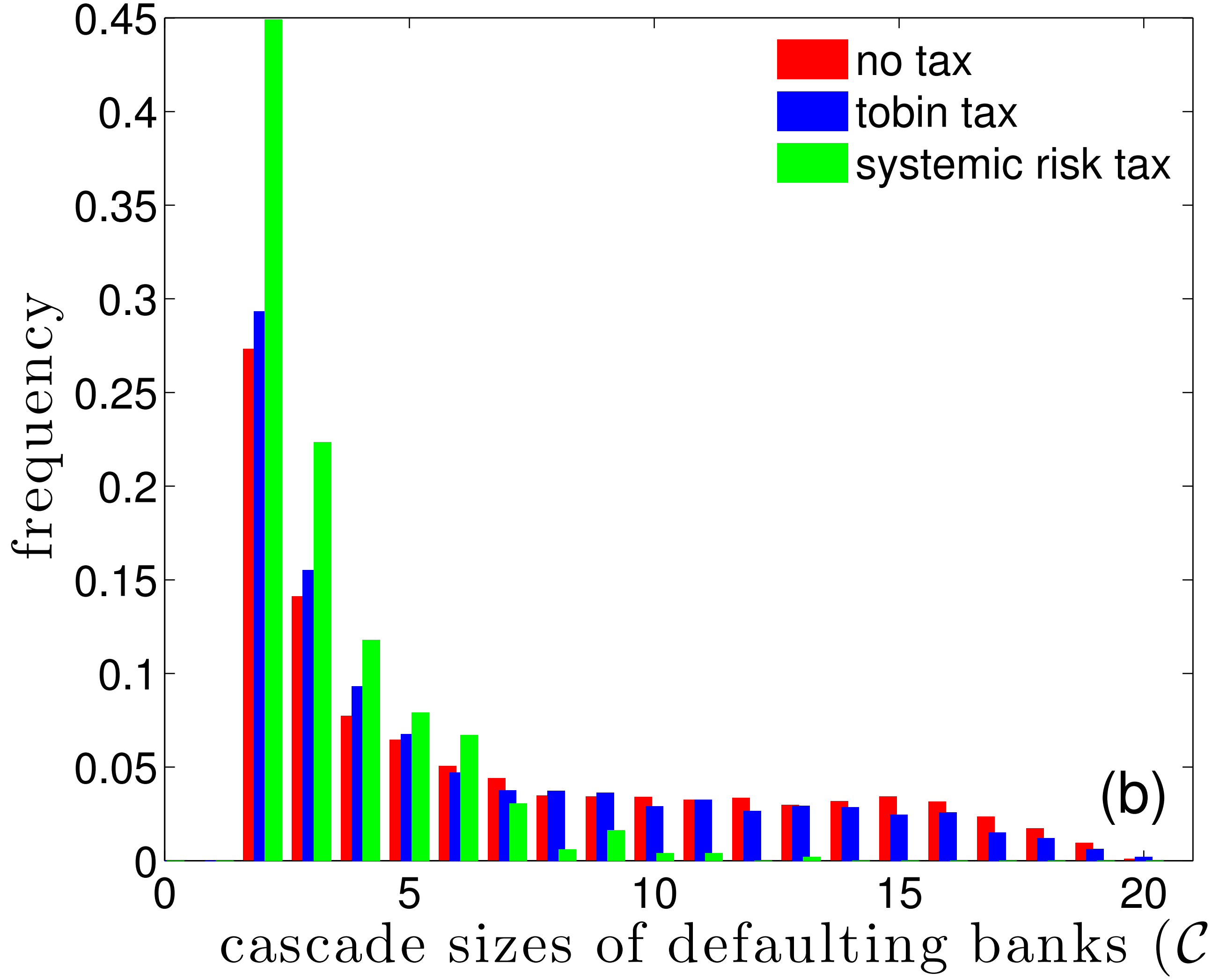


Model results: distribution of losses

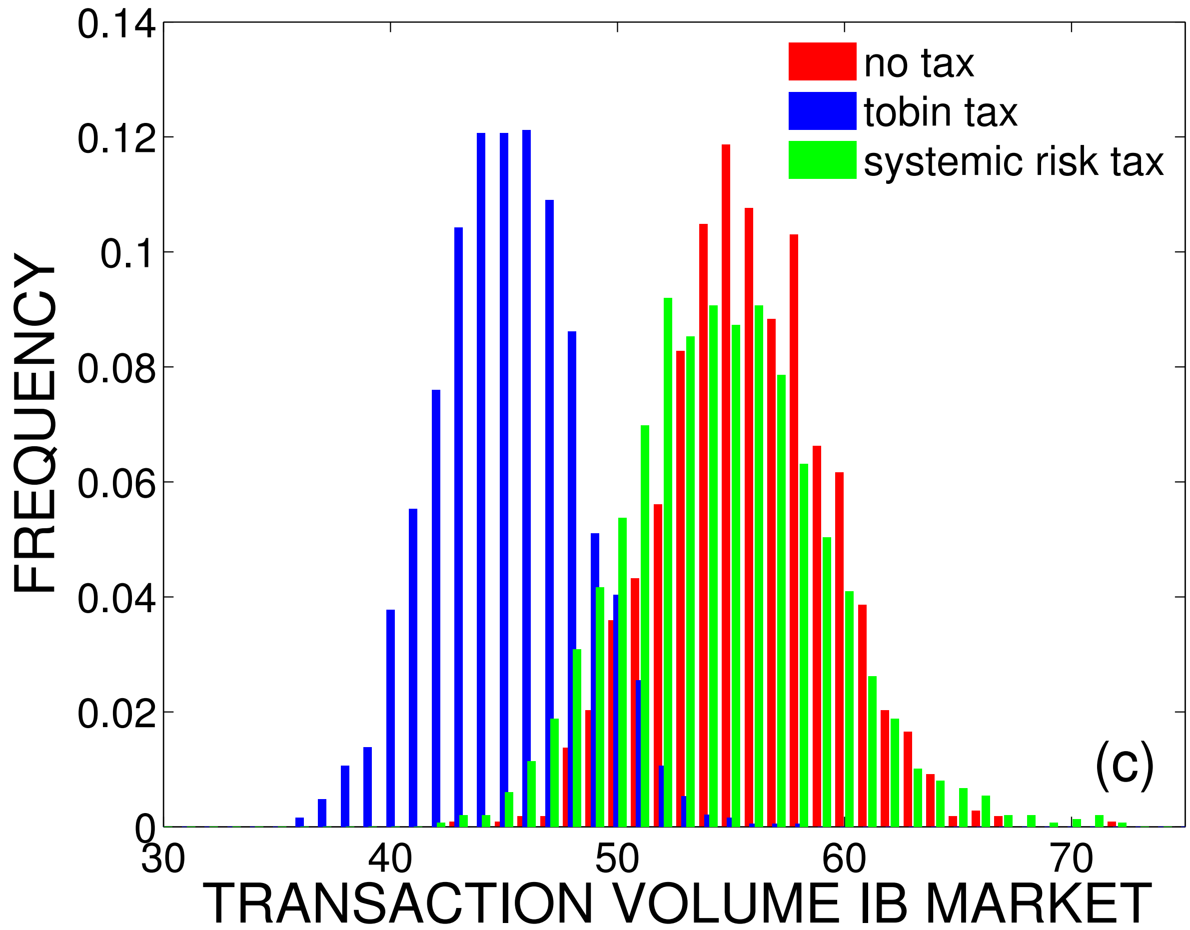


SRT eliminates systemic risk. How?

Model results: cascading is suppressed



Model results: credit volume



Tobin tax reduces risk by reducing credit volume

Basel III does not reduce SR

Basel III

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

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

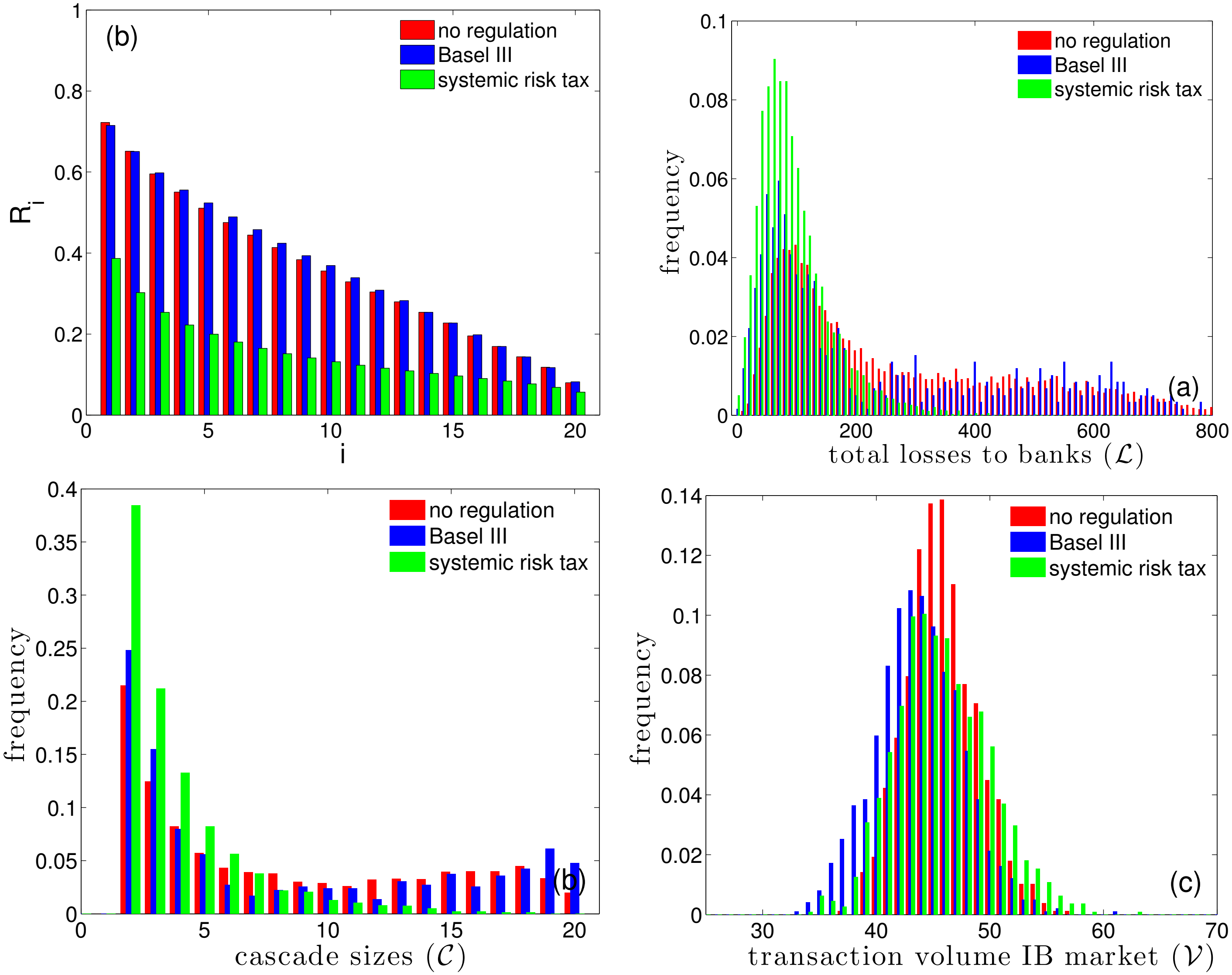
Bucket	Score range	Bucket thresholds	Higher loss-absorbency requirement
5	D-E	530-629	3.50%
4	C-D	430-529	2.50%
3	B-C	330-429	2.00%
2	A-B	230-329	1.50%
1	Cutoff point-A	130-229	1.00%

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

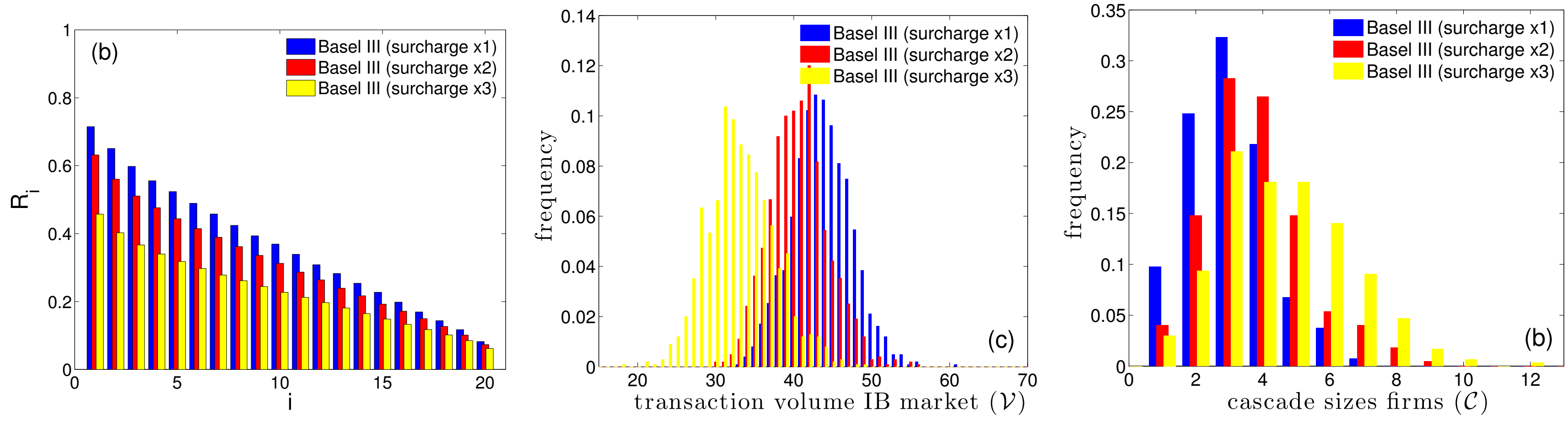
Basel III

- **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 does not reduce SR !

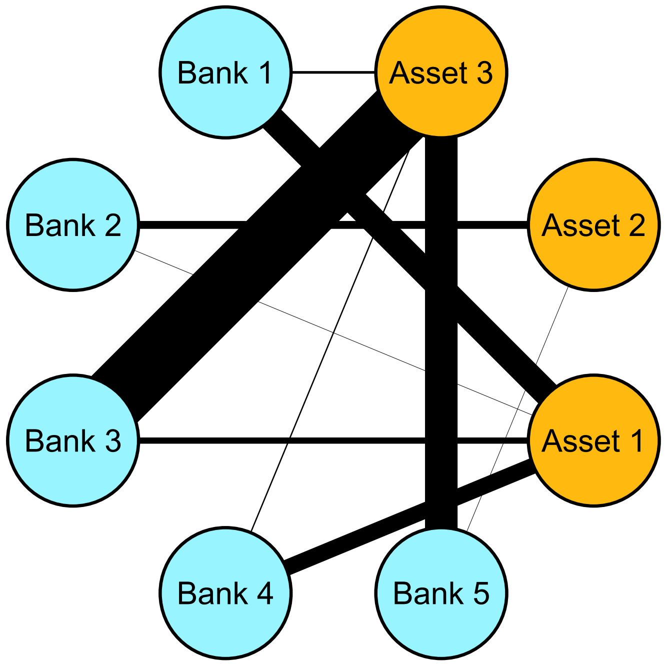


Basel III works under tremendous costs



What is the optimal network?

example: overlapping portfolio layer



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, $V_i = \sum_k \beta_{ki} p_k$

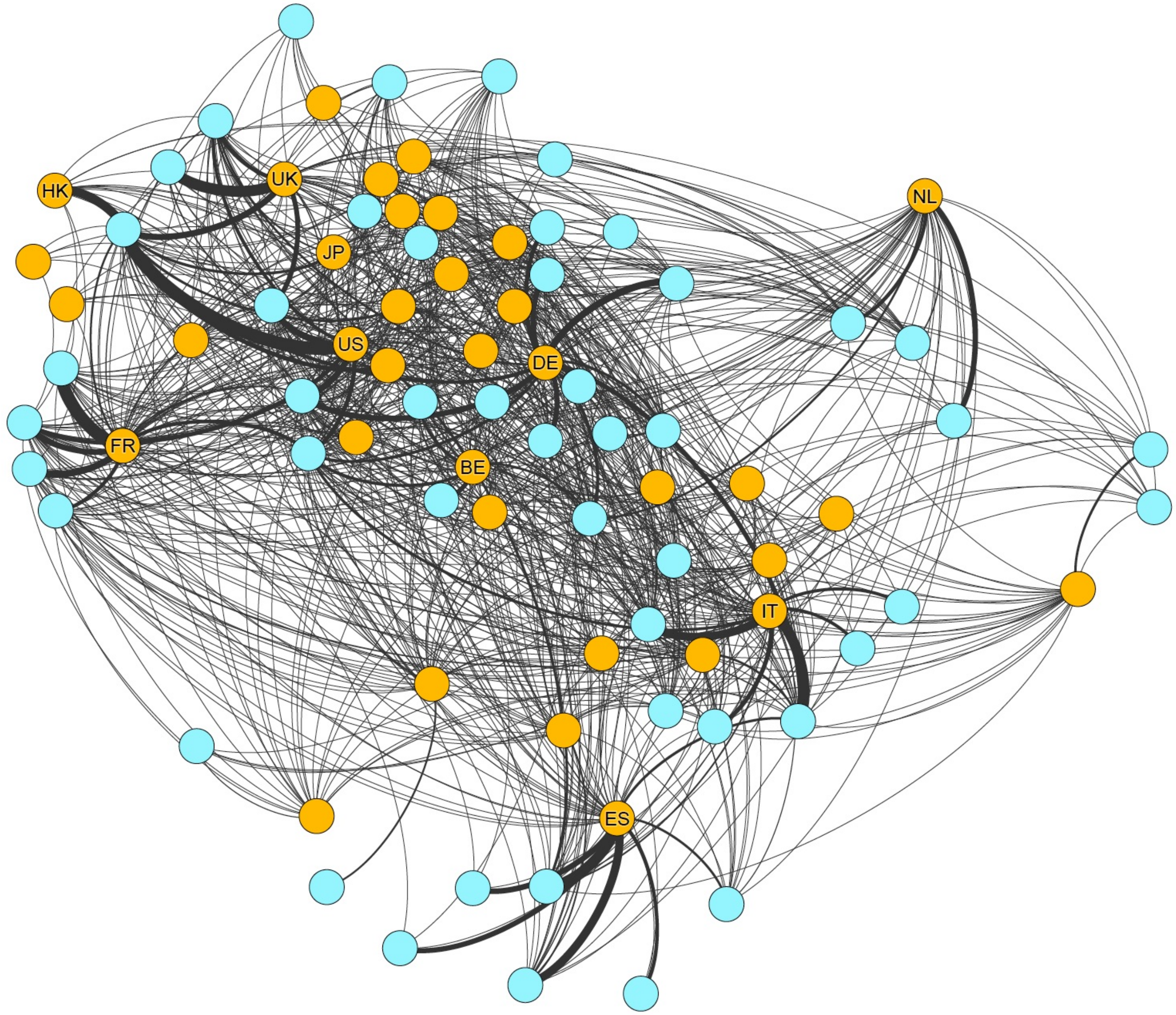
If bank i sells V_{ki} of asset k, price is depressed by $\frac{V_{ki}}{D_k}$

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

$$\rightarrow \; w_{ij} = \sum_{k=1}^{K} V_{kj} V_{ki} \frac{1}{D_k}$$

European stress testing data 2016 (EBA)

- 51 relevant European banks (49 included in analysis)
- 44 sovereign bond investment categories (36 included)


HK
UK
JP
NL
US
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Re-organize networks directly

Minimize SR, subject to portfolios get better

Quadratically Constrained Quadratic Programming problem

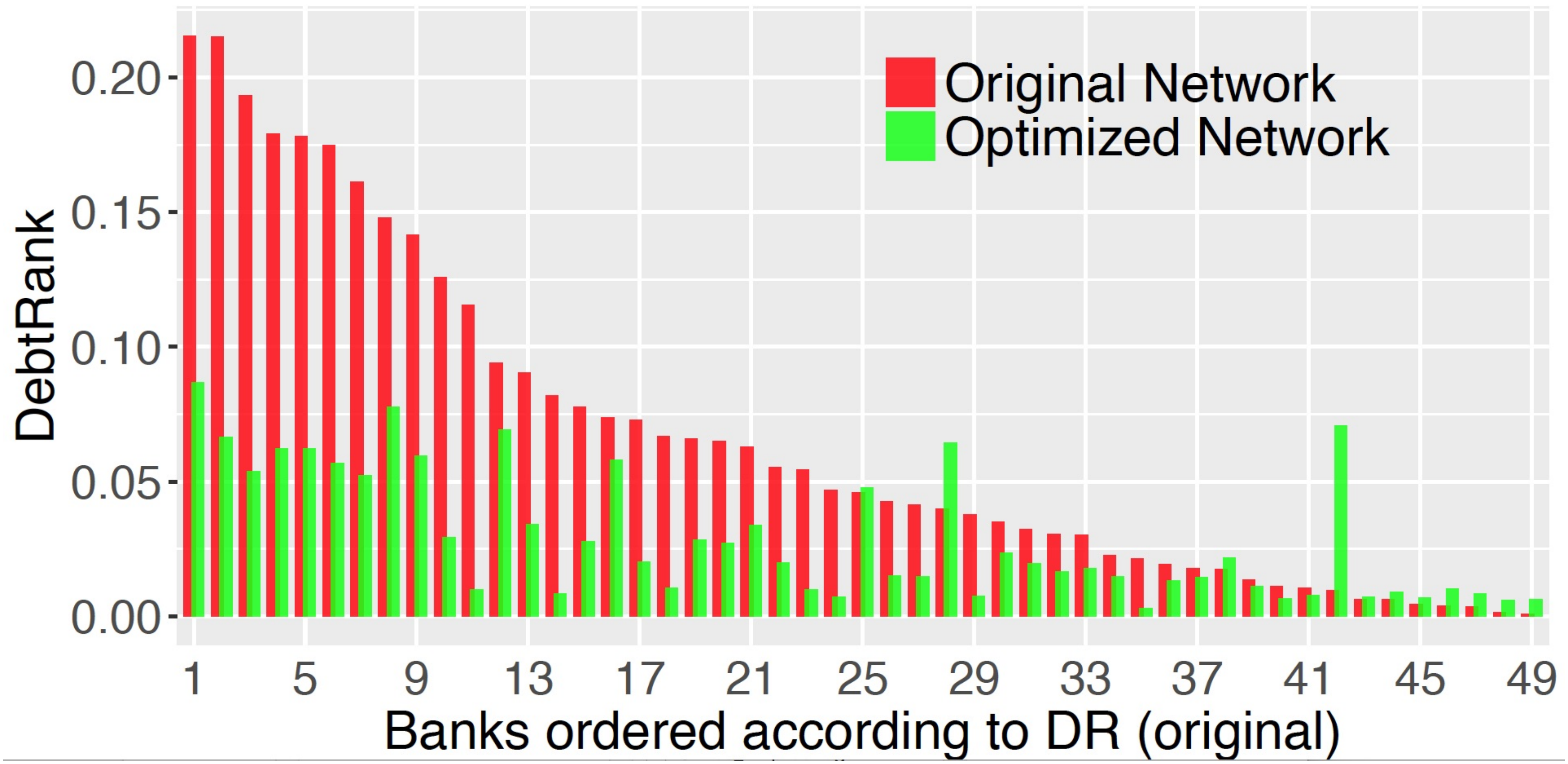
$$\min_{V_{ki}\geq 0\ \forall k,i} \quad f(x) = \sum_i \sum_j \frac{1}{C_j} \sum_k V_{ki} V_{kj} \frac{1}{D_k}$$

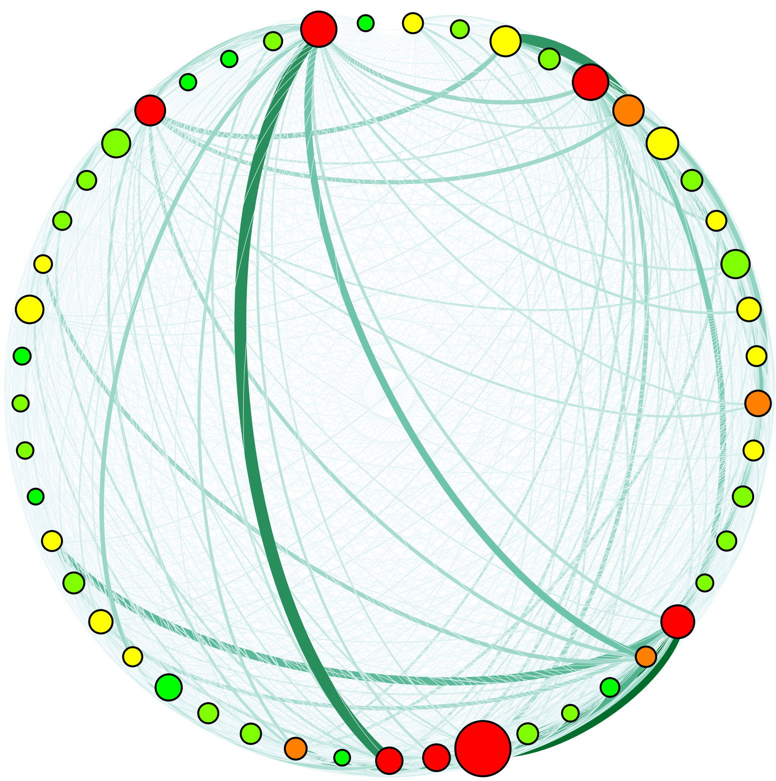
subject to $V_i = \sum_k V_{ki}, \quad \forall i,$

$$S_k = \sum_i V_{ki}, \quad \forall k,$$

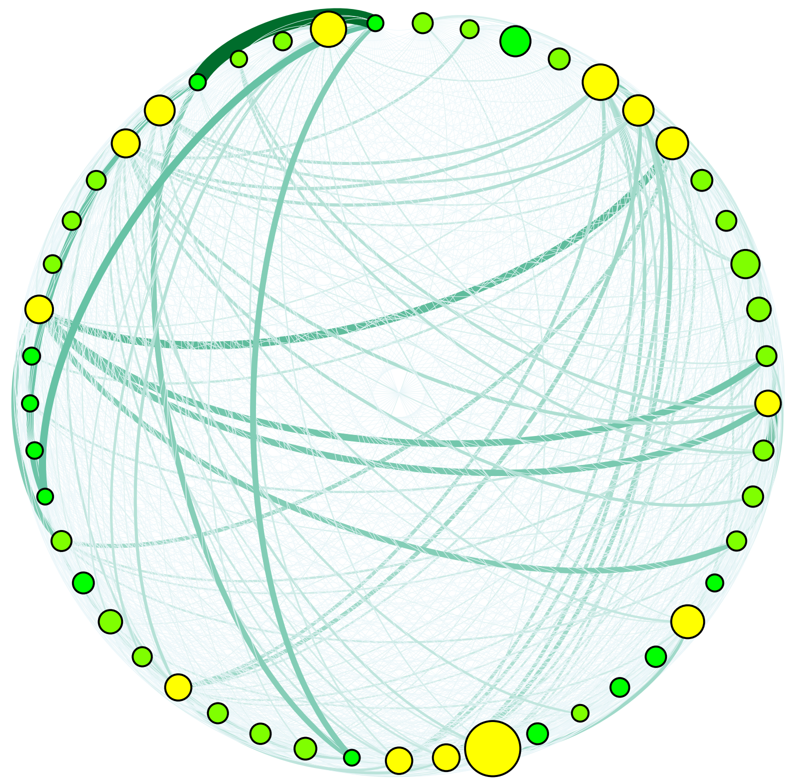
$$\tilde{r}_i \leq \sum_k V_{ki} r_k, \quad \forall i,$$ return not less

$$\tilde{\sigma}_i{}^2 \geq \sum_k \sum_l V_{ki} V_{li} \sigma_{kl}^2, \quad \forall i,$$ variance not more


Original Network
Optimized Network
DebtRank
0.20
0.15
0.10
0.05
0.00
1
5
9
13
17
21
25
29
33
37
41
45
49
Banks ordered according to DR (original)



original network



after optimization

Conclusions

- economies can be described without aggregation and statistics
- 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 does not reduce SR; 3-fold works
- SR tax is technically feasible

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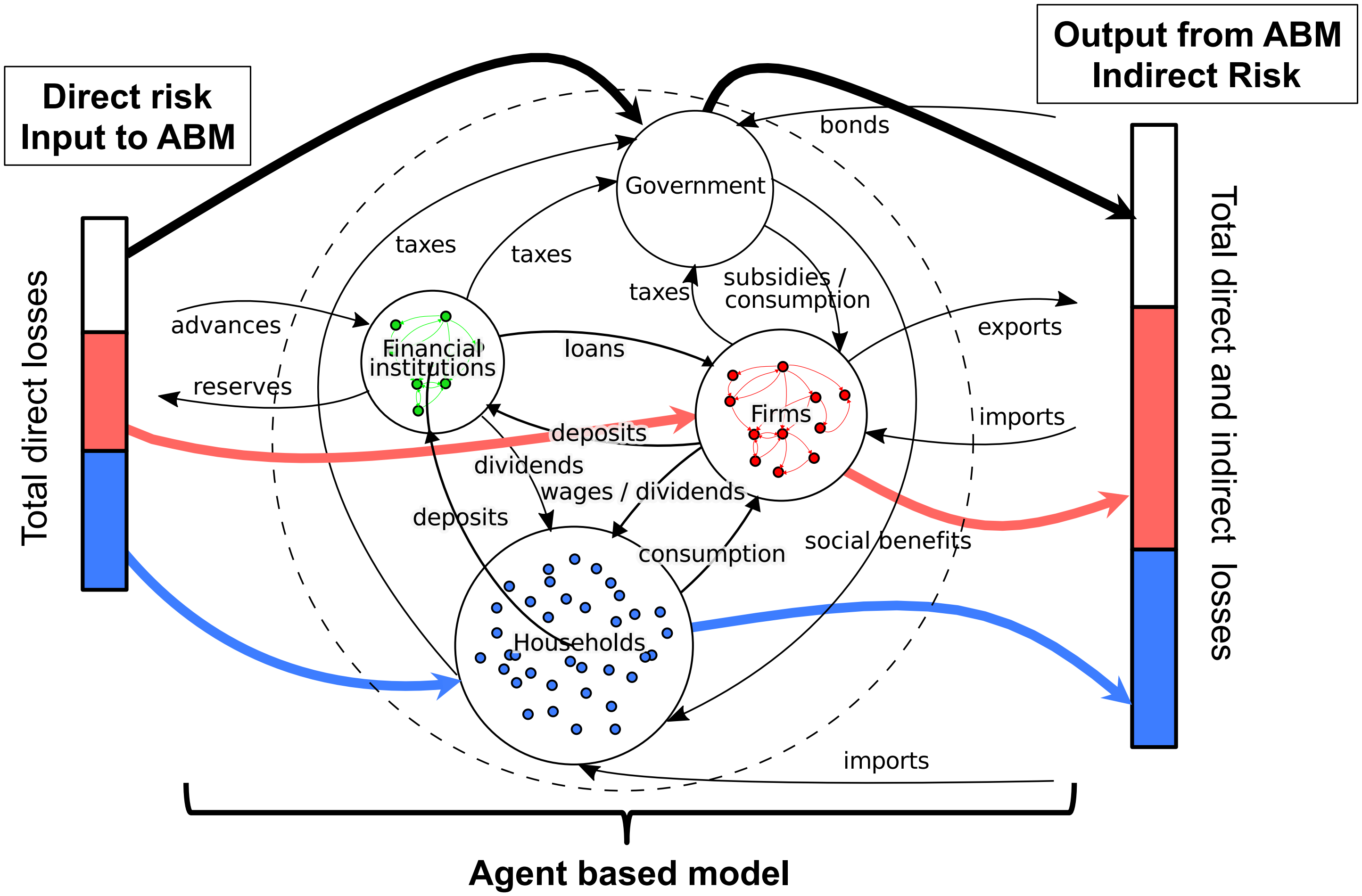
Systemic-risk-efficient asset allocation: Minimization of systemic risk as a network optimization problem, 2018 in review

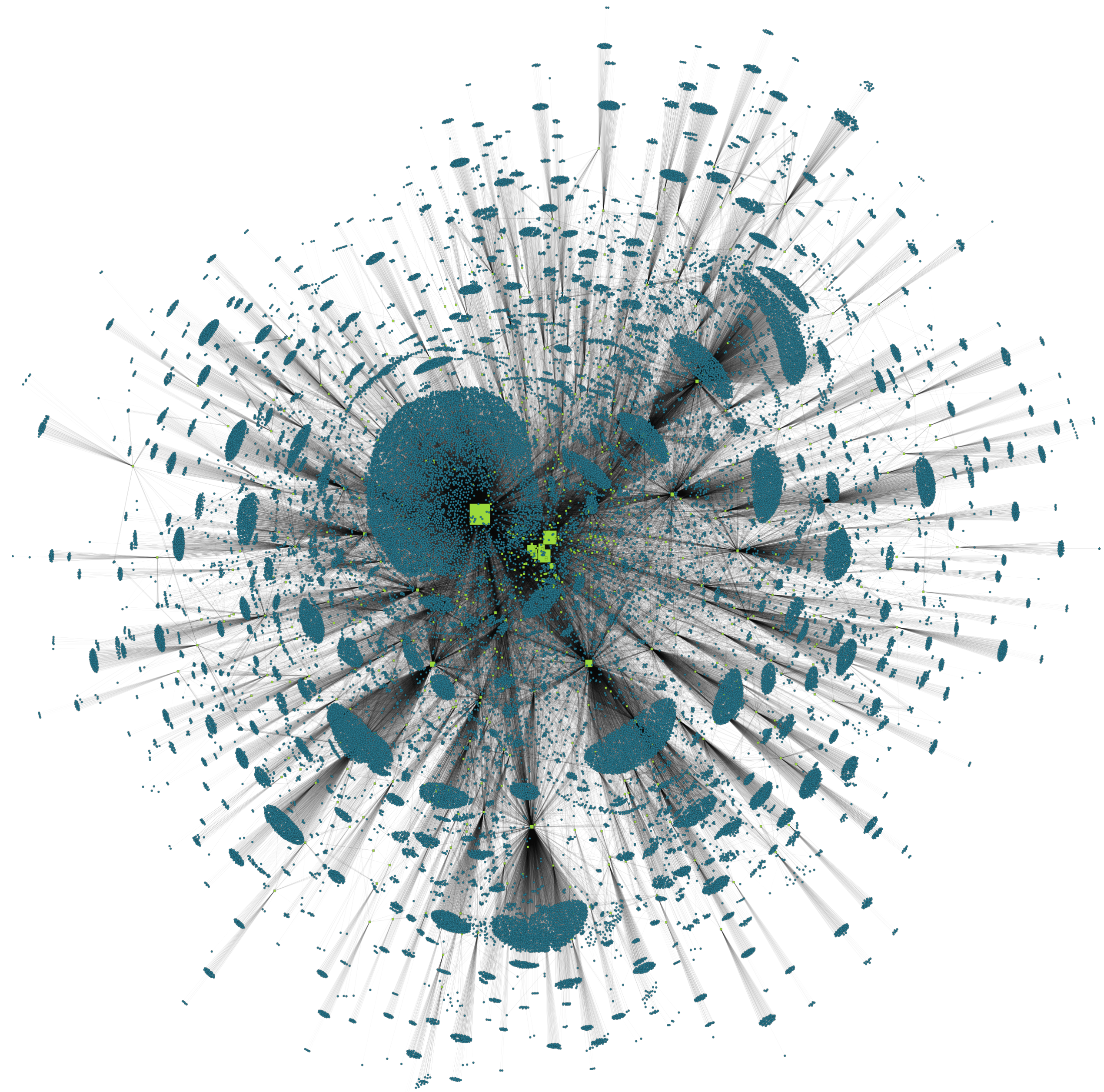
1:1 ABMs



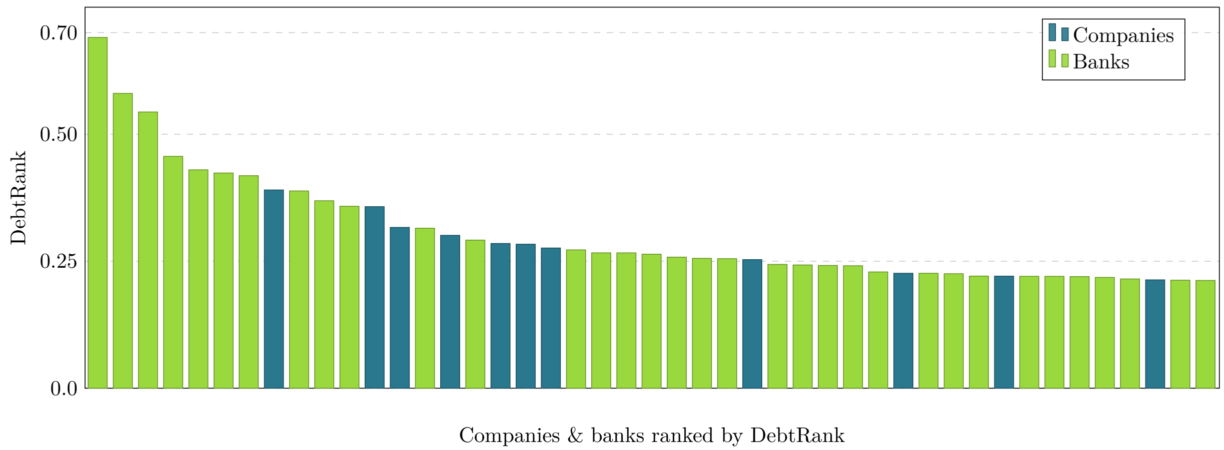
Direct risk
Input to ABM
Output from ABM
Indirect Risk
Total direct losses
Total direct and indirect losses
Government
Financial institutions
Firms
Households
taxes
taxes
taxes
bonds
subsidies / consumption
advances
reserves
loans
deposits
dividends
wages / dividends
deposits
consumption
social benefits
exports
imports
imports
Agent based model

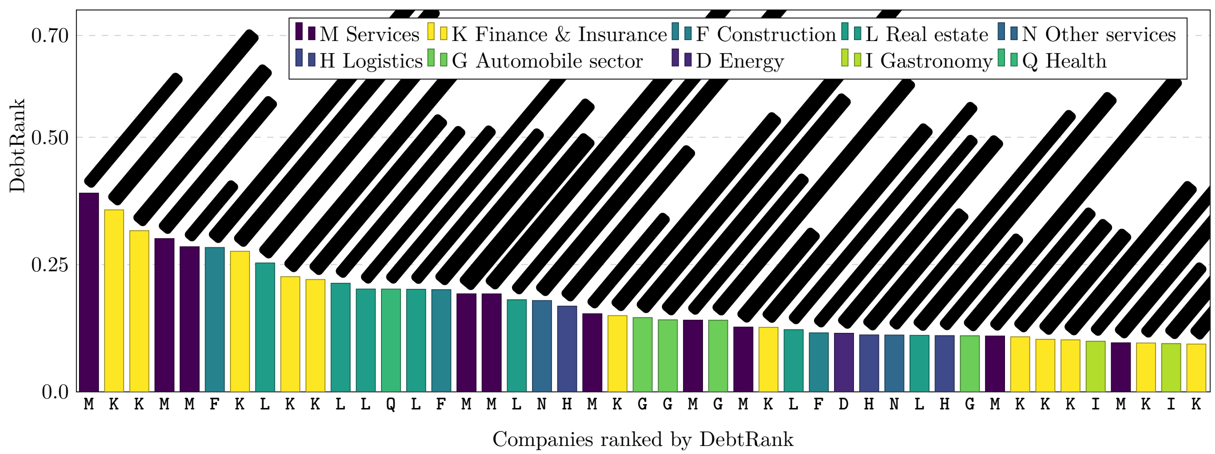
1:1 data-driven ABM of Austria

- 10 million households
- 200.000 companies (70.000 balance sheet histories)
- 1.000 banks
- 1000s of government agents



SR of companies

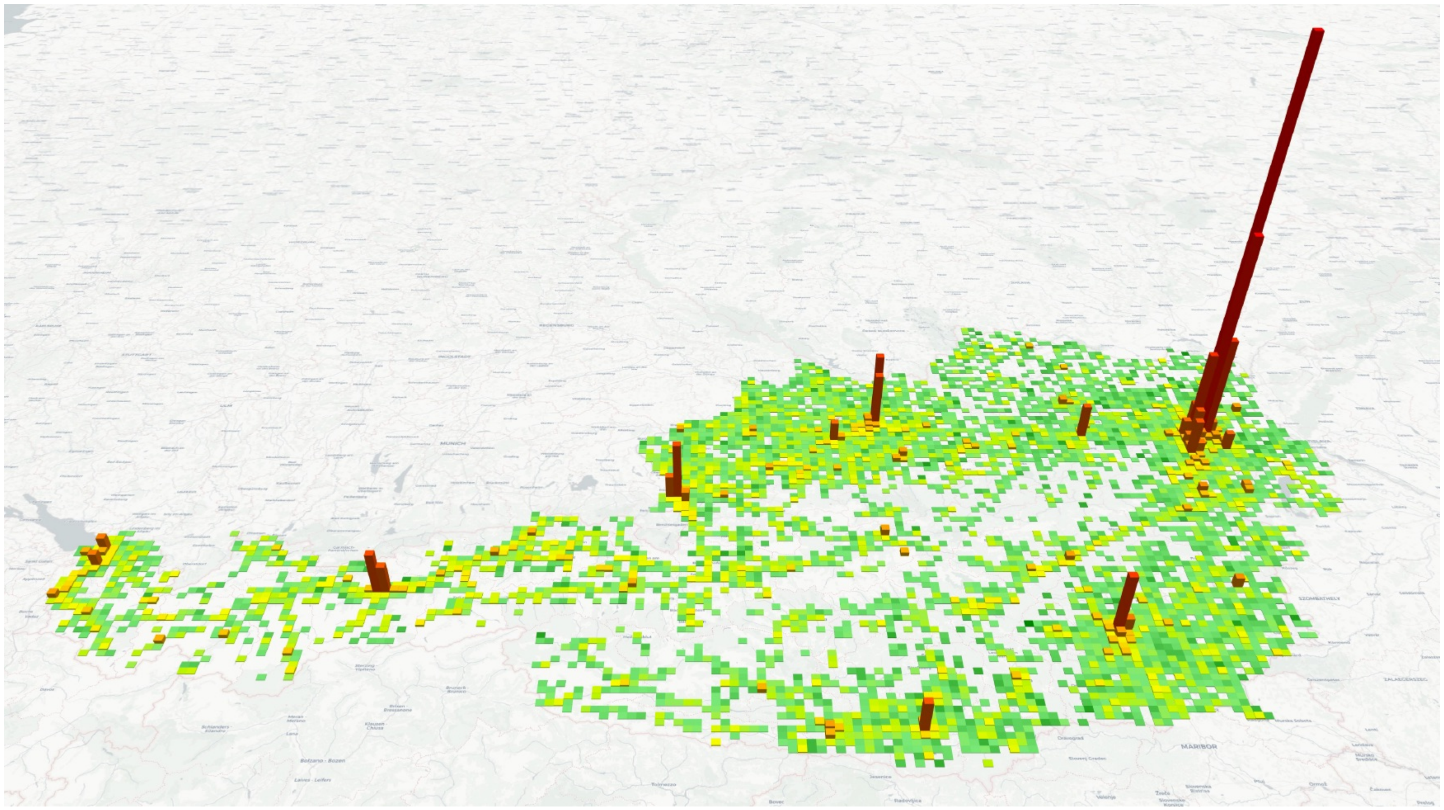




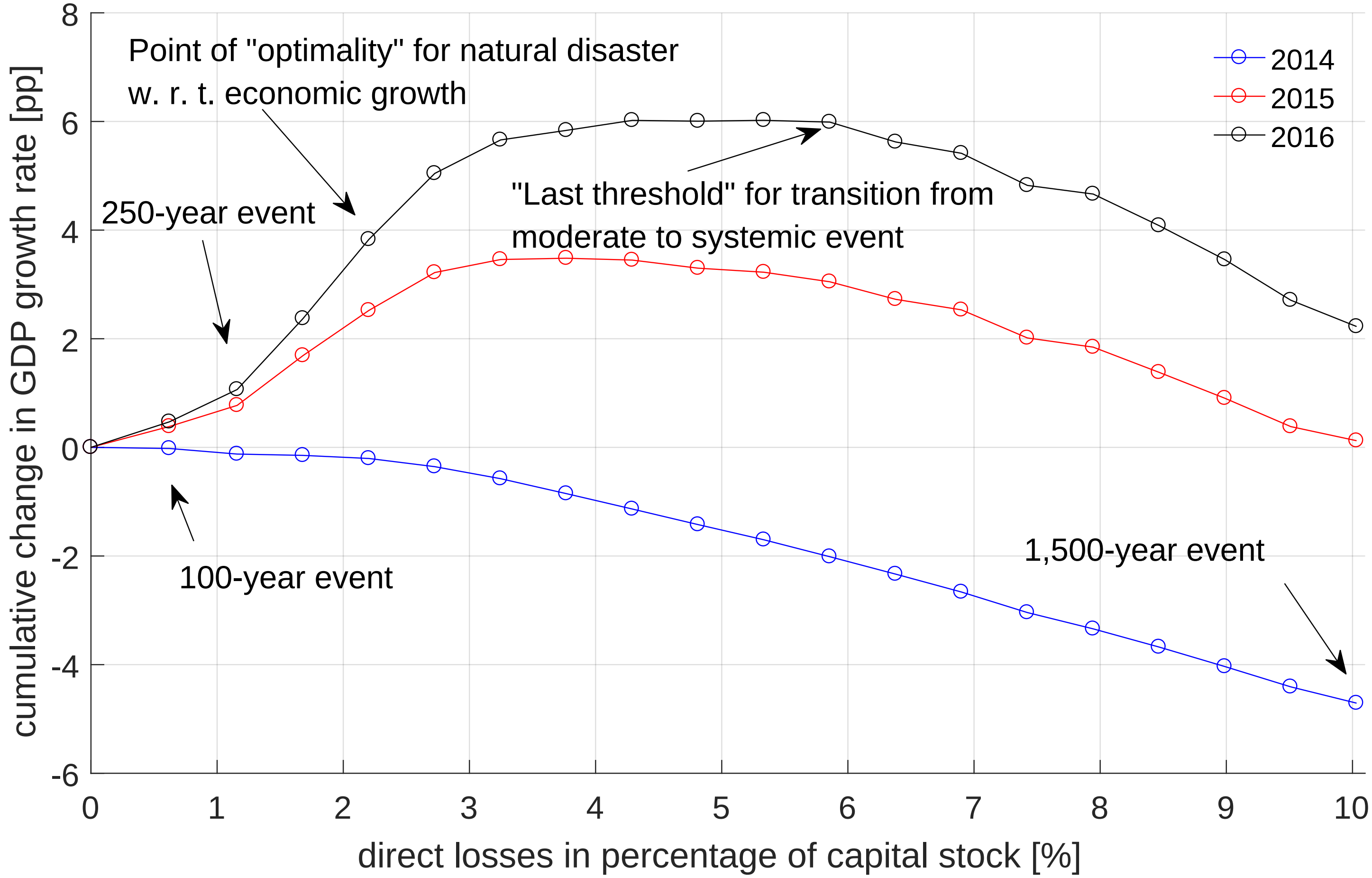
Message

more than half of the total financial SR comes from companies

1:1 ABMs in combination with external shocks



Optimal shock size? (preliminary)



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Alternatives to systemic risk tax

- Mandatory CDS

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

Problem 1 eigenvector is not economically reasonable number

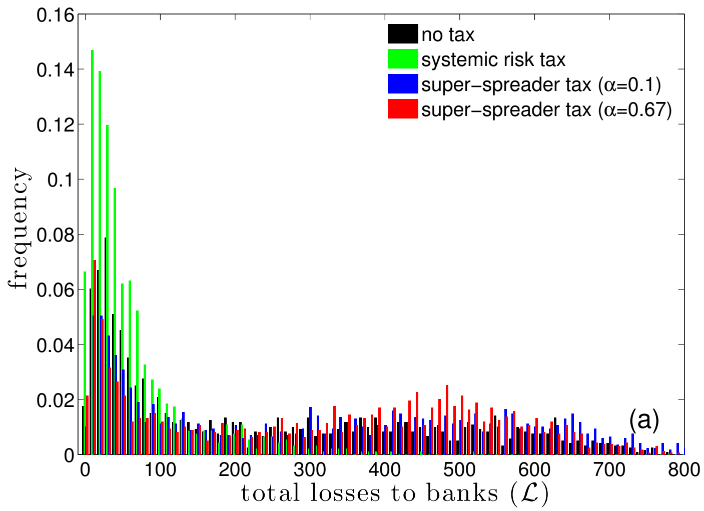
Problem 2 blind to cycles in contract networks

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

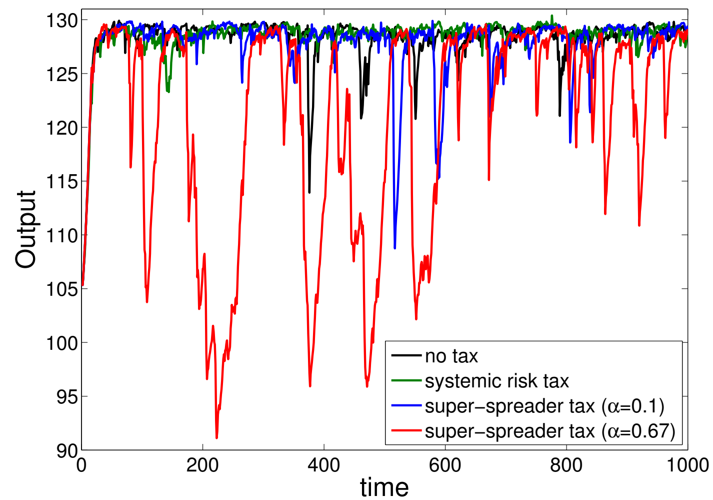
- Tax size: misses small SR institutions, SR improvement at tremendous economic cost

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