Quantification of systemic risk from overlapping portfolios in the financial system

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with Sebastian Poledna
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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

→ role of regulator: **manage systemic risk**
→ 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) $R_i \geq 0.02$

(b) $R_i < 0.2$

(c) $R_i < 0.15$

(d) $R_i < 0.1$

(e) $R_i < 0.05$

(f) $R_i < 0.01$

(g) $R_i < 0.005$

(h) $R_i < 0.0025$
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
Market depth and linear price impact

- market depth $D_k = c \frac{\langle \text{vol}_k \rangle_{\text{day}}}{\sigma_k}$

- 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 $k$ → face loss of $S_{kj} \frac{S_{ki}}{D_k}$

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

→ page is important if many important pages point to it

→ number for importance → **PageRank**
page is important if many important pages point to it
institutions risky. If 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 $W_{ij} = \min \left[ 1, \frac{L_{ij}}{C_j} \right]$, outstanding 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 $s_i(t) \in \{\text{Undistress, Distress, Inactive}\}$

- 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

Austria

![Bar graph showing Systemic Risk Profile for Austria](image)
Systemic risk profile

Mexico*

*with Serafín Martínez-Jaramillo and team at Banco de Mexico
Systemic risk profile from direct exposures

Mexico

*with Serafín Martínez-Jaramillo and team at Banco de Mexico
Systemic risk profile from overlapping portfolios

![Graph showing the systemic risk profile from overlapping portfolios.](b)
Exposures from direct exposures and overlapping portfolios

\[ \sum_{i,j} X_{ij}^{OP} \sim 1 \times 10^{12} \text{ Mex$} \]

\[ \sum_{i,j} X_{ij}^{\text{direct}} \sim 3.3 \times 10^{11} \text{ Mex$} \]
How big is the next financial crisis?
Expected systemic loss [Euro / Year]

\[
\text{Expected systemic loss} = \sum_i p_{\text{default}}(i) \cdot \text{DebtRank}(i)
\]

\[
\text{Expected loss}(i) = \sum_j p_{\text{default}}(j) \cdot \text{Loss-given-default}(j) \cdot \text{Exposure}(i,j)
\]
\[ \text{EL}^{\text{syst}} = V \sum_{S \in \mathcal{P}(B)} \prod_{i \in S} p_i \prod_{j \in B \setminus S} (1 - p_j) (R_S) \]
\[ \approx V \sum_{S \in \mathcal{P}(B)} \prod_{i \in S} p_i \prod_{j \in B \setminus S} (1 - p_j) \left( \sum_{i \in S} R_i \right) \]
\[ = V \sum_{i=1}^{b} \left( \sum_{J \in \mathcal{P}(B \setminus \{i\})} \prod_{j \in J} p_j \prod_{k \in B \setminus (J \cup \{i\})} (1 - p_k) \right) p_i R_i \]
\[ = V \sum_{i=1}^{b} p_i R_i \]
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

→ rational decision on bailouts

• allows to compare countries

• allows to compare situation of country over time

→ 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

$$\Delta EL^{syst}(\Delta X_{kl}) = \sum_{i=1}^{B} p_i [V(X_{ij} + \Delta X_{kl}) R_i(X_{ij} + \Delta X_{kl}, C_i) - V(X_{ij}) R_i(X_{ij}, C_i)]$$
Austria all interbank loans

note orders of magnitude!
Mexican data

\[ \Delta E L^{\text{syst}} > \Delta E L^{\text{credit}} \rightarrow \text{defaults do not only affect lenders but involves third parties} \]
Marginal systemic risk from overlapping pfs

\[ \Delta \text{EL}_{\text{syst}} \text{ [Mex$ / year]} \]

- indirect
- direct

exposure size [Mex$]

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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? \( \rightarrow \) increase of expected syst. loss

• ergo: restrict transactions with high systemic risk

\( \rightarrow \textbf{tax those transactions} \) 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 $\tau$, $r^f_{\text{loan}}$ → firms sell products to households: realise profit/loss → if surplus → deposit it bank accounts, for $r^f_{\text{deposit}}$ → 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)
Comparison of three schemes

- No systemic risk management
- Systemic Risk Tax (SRT)
- Tobin-like tax
Model results: Systemic risk profile

Austria

Model

(a) [Diagram showing systemic risk factor for Austria without tax, Tobin tax, and systemic risk tax]

(b) [Diagram showing systemic risk factor for the model with different tax scenarios]
Model results: Systemic risk of individual loans

Austria

Model
Model results: Distribution of losses

SRT eliminates systemic risk. How?
Model results: Cascading is suppressed

![Graph showing cascade sizes of defaulting banks for different tax scenarios: no tax, Tobin tax, systemic risk tax. The x-axis represents cascade sizes of defaulting banks (C), and the y-axis shows frequency. The graph indicates that cascading is suppressed under the systemic risk tax scenario.]
Model results: Credit volume

Tobin tax reduces risk by reducing credit volume
Mathematical proof:
SR-free equilibrium under SRT exists

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Reduce SR from overlapping portfolios?

→ see talk of Anton Pichler
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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