

# Financial Networks and Systemic Risk

Thesis supervised by Prof. Wolfgang E. Katzenberger

Christoph Siebenbrunner <sup>1,2</sup>  
christoph.siebenbrunner@oenb.at

<sup>1</sup>Institute of Management Science  
Vienna University of Technology

<sup>2</sup>Strategy & Stress Testing Unit  
Oesterreichische Nationalbank

Techno-Ökonomisches Kolloquium, TU Wien, November 2015

## Disclaimer

The views expressed herein are those of the presenter and do not necessarily reflect those of the OeNB or the ECB/ESCB.

# My work focusses on the role that financial networks and contagion effects play for systemic risk

## Definition of systemic risk (Cont. et al. 2010):

*(Systemic Risk) is concerned with the joint distribution of losses of all market participants and requires modeling how losses are transmitted through the financial system.*

Focus on loss transmission:

- Contagion effects
- Occur via financial networks

Out of focus:

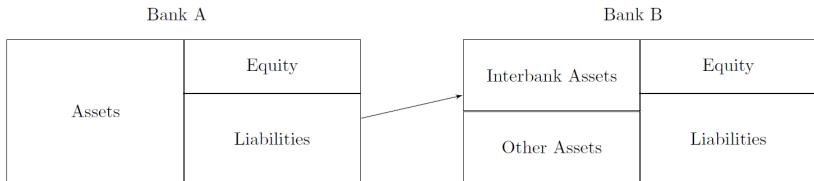
- Common exposures (included later)
- Collective behaviour
- Interactions with real economy

# Financial networks exist due to bilateral interbank exposures

Consider the following situation:

- Bank A has put all its assets into an investment project
- Part of bank's A investment is funded by a loan from B

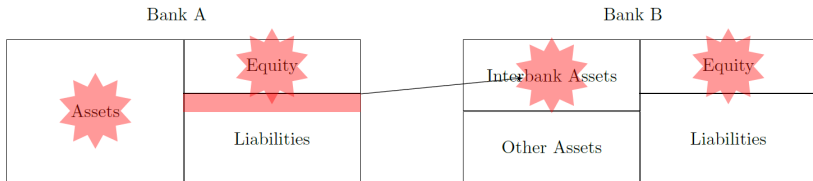
## Stylized interlinked Balance Sheets



**Linkages exist because anyone's liability is someone else's asset.**

# Contagion effects arise from write-downs of bilateral exposures after defaults

- Suppose bank A suffers loss greater than its equity
- Part of the loss born by B contagious shock to B's equity



## Default cascades:

- B is pushed into default due to the shock from A (contagious default)
- Will cause additional shock for creditors of B

# My work will explore why and how systemic risk should be regulated

Does the presence of systemic risk justify policy interventions?

If systemic risk should be regulated, how can it be measured?

Current policies already address systemic risk are they efficient?

# Agenda

- 1 Rational behaviour and welfare implications of systemic risk
- 2 Quantifying systemic risk contributions of different contagion channels
- 3 What do we need to know to regulate systemic risk? Are Basel III indicators sufficient?
- 4 Conclusion

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# The model considers social welfare and individual rationality

## Agent's choices:

- Threat of default cascades after idiosyncratic shocks
- Can be prevented by bailouts
- Agents use bailouts to maximise their equity value:

$$\max_{b_i} (e_i + b_i + (\Pi' p^*(b))_i - \bar{p}_i)$$

## Measuring social efficiency:

- Contagion effects only distribute losses across the system no loss at the aggregate level
- At individual level, losses are amplified due to leverage effects
- Policy makers want to minimize the sum of these losses:

$$\max_b (\vec{1}' (p^*(b) - \Lambda(p^*(b))b))$$

# Results show that there exists a social dilemma in the presence of contagion effects

## **Theorem 1:**

Bailouts are generally (under mild conditions) socially efficient.

## **Theorem 2:**

Initial losses are equal to contagion losses incurred by surviving banks plus equity value of banks pushed into contagious defaults.

**Corollary:** A pareto-efficient solution for bailouts exists that is rational for all agents (some gain, some are indifferent).

## **Theorem 3:**

The unique Nash equilibrium when a bailout is played as a non-cooperative game is that no-one contributes to the bailout (freerider problem)

## Conclusion: Systemic risk should be regulated

- If policy makers care about total losses in the system, bailouts are generally socially efficient
- A pareto-efficient solution exists where bailouts funded by the private sector are rational for all agents in the system
- Without a intervention, socially efficient bailouts are not realized due to freerider problem

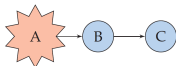
**The presence of a social dilemma in the context of systemic risk justifies a policy intervention.**

# Agenda

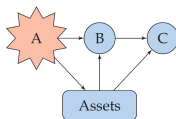
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# I introduce a general framework for quantifying the effects of three different contagion channels

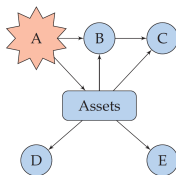
Direct contagion



Asset Fire Sales



Mark-to-Market Effects



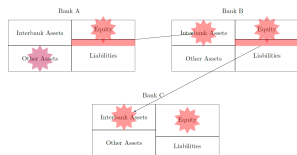
- **Direct contagion:** effects of writedowns on bilateral exposures, without haircuts
- **Asset fire sales:** liquidation losses (value of assets after default is lower than book value)
- **Mark-to-Market effects:** all market participants have to recognize lower market prices on asset holdings

# The model used accounts for all possible default cascades and computes the market equilibrium after fire sales

## Direct contagion effects: ▶ Model

- In equilibrium, everybody repays the minimum of his liabilities and his or her remaining assets
- Fixed point problem :

$$\Phi_1(p)_i = \begin{cases} \bar{p}_i & \text{if } \bar{p}_i \leq e_i \Gamma_{ii} + (\Pi' p)_i \\ \alpha e_i \Gamma_{ii} + \beta (\Pi' p)_i & \text{otherwise} \end{cases}$$

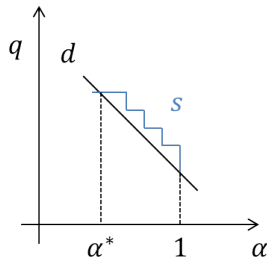


## Asset fire sales: ▶ Model

- Defaulted banks have to sell their assets
- The more banks default, the more assets are liquidated, the lower the price
- Inverse demand function:

$$\alpha(p, \Gamma) = 1 - \kappa * \frac{s}{\sum_{i=1}^n e_i}$$

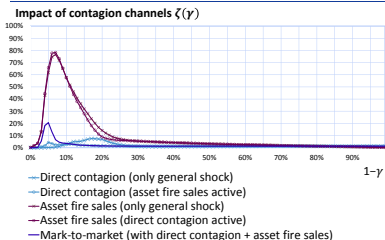
Similar dynamics under MtM, but higher losses



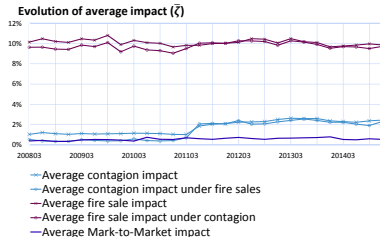
# Results show that asset fire sales are the most important contagion channel

Model was evaluated using quarterly Austrian interbank data from 2008Q1 to 2014Q4

## Impact of contagion channels



## Evolution over time



## Conclusion: Quantitative measures for systemic risk

- I introduced a general framework for measuring the effects of three different contagion channels
- The effects of direct contagion, asset fire sales and mark-to-market effects were evaluated using Austrian interbank data from 2008 to 2014
- Asset fire sales were found to be the most significant channel across time

**The framework allows for measuring the impact of different contagion channels.**

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Joint work with Stefan Kerbl and Michael Sigmund (both OeNB)

## Basel III introduces capital buffers for systemically important financial institutions (SIFIs)

### Basel III:

- Capital surcharge for systemically important financial institutions (SIFIs)
- Indicators for identifying SIFIs (focus on Domestic SIFIs):

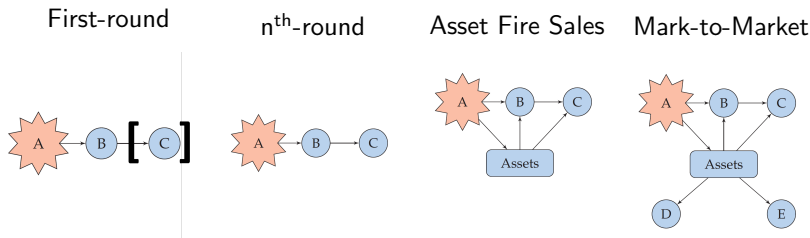
Total assets, Nonbank deposits, Loans to nonbanks, OTC derivatives, Loans to foreign customers, Deposits from foreign customers, Bank deposits, Bank loans, Securitized debt

All are bank-level metrics!

**Can bank-level regulatory indicators capture network and other contagion effects?**

# We test whether Basel III indicators are successful at capturing contagion effects

Direct contagion is split into first- and  $n^{\text{th}}$ -round contagion



## Contagion measures:

- Let each bank default consecutively
- Systemic risk contribution is the impact of one bank on the entire system. Metrics:
  - Number of contagious defaults (unweighted)
  - Total assets of defaulted banks (weighted)
  - Total losses caused

## Our analysis also looks beyond Basel III indicators

Contagion metrics used as dependent in fixed-effect panel regression:

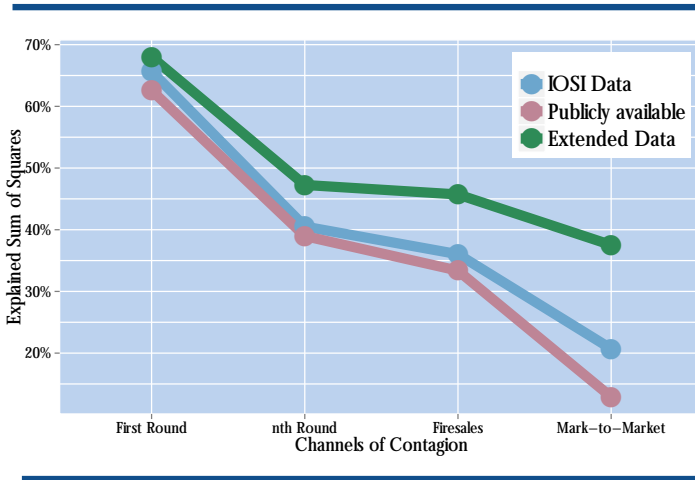
$$y_{i,t} = \beta_0 + \beta' X_{i,t} + u_{i(t)} + e_{i,t}$$

RHS variables: different sets of bank-level indicators: [▶ Annex](#)

- Publicly available data
- Basel III indicators
- Extended data set, using simple network metrics that can be observed at the bank level

We use model selection with  $k = 9$  variables (number of Basel III indicators), to ensure that only models of equal size are compared.

# Results show that Basel III indicators fail to capture contagion effects



## Conclusion: Current systemic risk regulations do not capture important contagion effects

- Current regulations are based on bank-level metrics
- Bank-level metrics can satisfyingly capture first-round contagion effects
- Bank-level metrics (even those including network measures observable at the bank level) are not efficient at capturing higher-order network and other contagion effects

**Systemic risk regulation should include network information to account for contagion effects.**

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# Conclusion

Welfare analysis shows that systemic risk should be regulated

- Existence of a social dilemma in the presence of contagion effects
- Efficient solutions exist, but cannot be realized without policy interventions

Hence, we need a framework for measuring systemic risk

- Developed framework for measuring direct contagion, asset fire sales and mark-to-market effects
- Asset fire sales were found to be most significant channel

Which allows for assessing systemic risk regulations

- Basel III indicators cannot capture higher-order network or other contagion effects
- Systemic risk regulation should use network information

# Acknowledgements

This work was presented and benefitted from discussions with participants at the following conferences:

- Austrian Working Group on Banking and Finance, 22-23 November 2013, Vienna
- IISES International Academic Conference, 21 June 2015, Vienna
- Financial Risk & Network Theory, 9 September 2015, University of Cambridge
- Conference on Systemic Risk Analytics, 23-25 September 2015, RiskLab/Bank of Finland/European Systemic Risk Board, Helsinki (poster presentation by Stefan Kerbl)
- Network models, stress testing and other tools for financial stability monitoring and macroprudential policy design and implementation, Banco do Mexico/University of Zürich/Journal of Financial Stability/CEMLA, Mexico City (poster presentation)

Further discussions were held at seminars at the the European Central Bank, Oesterreichische Nationalbank, TU Vienna and at the Techno-Ökonomischem Kolloquium at TU Graz. Further tanks go to my co-authors Stefan Kerbl and Michael Sigmund for their contributions as well as Helmut Elsinger (OeNB) for helpful comments.

Systemic risk  
oooo

Should we regulate it?  
ooo

How to measure it  
oooo

How to regulate it  
ooooo

Conclusion  
oo

# Annex

# Balance sheet framework

## Variable definitions from Elsinger 06

- Interbank loan matrix  $L$ , where  $L_{ij}$  is the amount  $i$  owes to  $j$
- Total liabilities vector  $\bar{p}_i = \sum_{j=1}^n L_{ij}$
- Relative liabilities matrix  $\Pi_{ij} = \begin{cases} \frac{L_{ij}}{\bar{p}_i} & \text{if } \bar{p}_i > 0 \\ 0 & \text{otherwise} \end{cases}$
- Vector  $e$  of assets other than interbank claims/liabilities
- Insolvent firms cannot repay liabilities in full
- Value of interbank claims for creditors given by  $\Pi'p$  for arbitrary payment vector  $p$

# Balance sheet framework

Balance sheet of firm  $i$  under payment vector  $p$ :

Interbank assets $(\Pi'p)_i$	Equity $e_i + (\Pi'p)_i - \bar{p}_i$
Other assets $e_i$	Liabilities $\bar{p}_i$

# Direct contagion effects

Eisenberg/Noe

- Solvent firms repay their liabilities in full
- Insolvent firms split remaining value of assets of among creditors
- Losses for creditors may cause default cascades
- Circular cascades create fixed point problem
- Solution: **clearing payment vector**  $p^*$ :

$$p_i^* = \begin{cases} \bar{p}_i & \text{if } \bar{p}_i \leq e_i + (\Pi' p^*)_i \\ e_i + (\Pi' p^*)_i & \text{otherwise} \end{cases}$$

- Value of consolidated system does not change

▶ Presentation: Welfare Model

▶ Presentation: Contagion Channels

# Asset fire sales

Rogers/Veraart

- Banks invest in illiquid assets  $\rightarrow$  liquidation losses
- Recovery value  $\alpha \in [0, 1]$  for other/illiquid assets  $e$
- Recovery value  $\beta \in [0, 1]$  for interbank claims
- Clearing payment vector under fire sales: fixed point  $p^* = \Phi(p^*)$  of the map:

$$\Phi(p)_i = \begin{cases} \bar{p}_i & \text{if } \bar{p}_i \leq e_i + (\Pi' p)_i \\ \alpha e_i + \beta (\Pi' p)_i & \text{otherwise} \end{cases} \quad (1)$$

- Value of consolidated system is reduced by

$$\sum_{\{i: p^* < \bar{p}\}} ((1 - \alpha)e_i + (1 - \beta)(\Pi' p^*)) \quad (2)$$

# Asset fire sales

## Proposition

The value of the financial system is bounded below by 0 iff  $\beta = 1$

## Proof

Value of the entire system after contagion losses citeRogers2013:

$$\sum_{i=1}^n e_i - \sum_{\{i: p_i^* < \bar{p}_i\}} ((1 - \alpha)e_i + (1 - \beta)(\Pi' p)_i) \quad (3)$$

With  $\beta < 1$  this value is negative when:

$$\sum_{i=1}^n e_i - \sum_{\{i: p_i^* < \bar{p}_i\}} (1 - \alpha)e_i < \sum_{\{i: p_i^* < \bar{p}_i\}} (1 - \beta)(\Pi' p)_i \quad (4)$$

→ Set  $\beta = 1$  for the remainder of the paper

# Loss correlation

Cifuentes et al.

- Include idiosyncratic and general shocks
- Captured in diagonal shock matrix  $\Gamma$
- $\Gamma_{ii}$  is the remaining value of illiquid asset holdings of bank  $i$
- Clearing payment vector  $p^{*,1}(\alpha, \beta, \Gamma)$  as fixed point of the map:

$$\Phi_1(p)_i = \begin{cases} \bar{p}_i & \text{if } \bar{p}_i \leq e_i \Gamma_{ii} + (\Pi' p)_i \\ \alpha e_i \Gamma_{ii} + \beta (\Pi' \bar{p})_i & \text{otherwise} \end{cases} \quad (5)$$

## Asset fire sale endogeneities

- Let  $\alpha$  depend on the amount of overall fire sales
- Assume inverse demand function:

$$d^{-1}(p, \Gamma) = \alpha(p, \Gamma) = 1 - \frac{\sum_{\{i \in \mathcal{N} : \Gamma_{ii} e_i + (\Pi' p)_i < \bar{p}_i\}} e_i}{\sum_{i=1}^n e_i} \quad (6)$$

- Equilibrium price for the common asset given by the fixed point  $\alpha^{*,1}(\Gamma)$  of the map:

$$\Theta_1(\alpha) = d^{-1}(p^{*,1}(\alpha, \beta, \Gamma), \Gamma) \quad (7)$$

where

$$p^{*,1} = \Phi_1(p^{*,1}) \quad (8)$$

- Convergence is guaranteed by the continuity of the inverse demand function

# Variables used for estimating contagion output

▶ Presentation

Name	Description	Normalized by total assets	IOSI	Publicly available
Log total assets	Logarithm of total assets	No	Yes	Yes
Nonbank deposits	Deposits taken from domestic and foreign nonbanks (i.e. customers), all currencies	Yes	Yes	Yes
Loans to nonbanks	Loans to foreign and domestic nonbanks	Yes	Yes	Yes
OTC derivatives	Notional value of OTC derivatives	Yes	Yes	Yes
Loans to foreign customers	Loans to foreign domiciled nonbanks and banks	Yes	Yes	Yes
Deposits from foreign customers	Deposits from foreign domiciled nonbanks and banks	Yes	Yes	Yes
Bank deposits	Deposits taken from domestic and foreign banks, all currencies	Yes	Yes	Yes
Bank loans	Loans to domestic and foreign banks, all currencies	Yes	Yes	Yes
Securitized debt	Liabilities in the form of securitized debt obligations and transferable certificates	Yes	Yes	Yes
Net interest margin	Net interest income over total assets	by definition	No	Yes
Interest rate nonbank loans	Average interest rate on nonbank loans	No	No	No
Interest rate bank loans	Average interest rate on bank loans	No	No	No
Interest rate nonbank deposits	Average interest rate on nonbank deposits	No	No	No
Interest rate bank deposits	Average interest rate on bank deposits	No	No	No
LLP ratio	Specific loan loss provisions over gross exposure (loans to domestic and foreign nonbanks, all currencies), smoothed	No	No	Yes
Tier 1 capital ratio	Eligible tier 1 capital over RWA	by definition	No	Yes
Tier 1 capital ratio credit risk	Eligible tier 1 capital over RWA for credit risk	by definition	No	Yes
Leverage ratio	Eligible tier 1 capital over total assets	by definition	No	Yes
RWA	Total risk-weighted assets	Yes	No	Yes
RWA credit risk	risk-weighted assets (credit risk only)	Yes	No	Yes
Net fee income	Net fee and commission income (smoothed)	Yes	Yes	Yes
Interest-bearing securities	Exchange-traded interest-bearing securities (held as assets) issued by domestic and foreign banks and nonbanks, all currencies	Yes	No	Yes
Staff expenses	Staff expenses	Yes	No	Yes
Other operating expenses	Operating expenses other than staff expenses	Yes	No	Yes
N-Ingoing Links	Number of bank deposits	No	No	No
N-Outgoing Links	Number of bank loans	No	No	No