Bank Networks:

Contagion, systemic risk and prudential policy

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Introduction

Motivation

- Relatively small losses due to sub-prime mortgage defaults in the US propagated through the financial system to cause a global banking crisis in 2007-2008.
- Propagation channels included:
    - liquidity hoarding due to banks' precautionary behavior,
    - direct linkages in interbank markets,
    - indirect linkages through overlapping portfolios that can lead to fire sale externalities.
- Regulation that attempts to stabilize the banking system needs to take into account its impact on these propagation channels.
- Regulation typically entails a trade-off between achieving stability and allowing the banking sector to fulfill its function of providing sufficient funding to the real economy.

Contribution to the Literature

- The paper develops a banking network model with optimizing heterogeneous banks.
- Propagation channels of financial stress can be jointly examined, which is a rare feature in the literature.
- Liquidity and capital regulation is introduced into the setup. The authors analyze the trade-off between its impact on stability and efficiency.

Related Literature

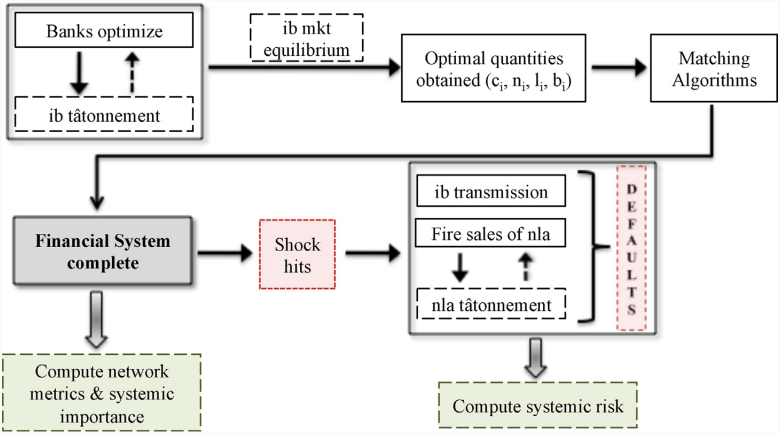
- The paper is related to the literature analyzing contagion using network models, which has surged in the aftermath of the global financial crisis.
- Important contributions include:
    - Eisenberg and Noe (2001), who analyze the transmission of shocks through direct linkages in the network using a lattice-theoretic model and solving for a unique fixed-point.
    - Greenwood et al. (2015), who study fire sale dynamics due to asset commonality and mark-to-market accounting.
- The paper is related to the literature that looks at liquidity hoarding in the face of stress. Contributions include e.g. Afonso and Shin (2015) and Acharya and Merrouche (2013).

The Model

Model Components

- Banks are nodes in the network model and the links between nodes represent the borrowing and lending relationships.
    - The network is weighted, i.e. the links represent the money amount of the credit relationship.
    - The network is directed, i.e. lending and borrowing are not represented by the same link.
- Banks' asset side consists of (1) interbank assets and (2) external (non-interbank) assets, i.e. cash and non-liquid assets.
- Their liability side consists of (1) interbank loans, (2) deposits and (3) equity.
- Heterogeneity is included through different (1) returns on non-liquid assets and exogenously set levels of (2) equity and (3) deposits.
- Prices clear the interbank market and the market for non-liquid assets. They are determined endogenously through a tatonnement process.
- Trading quantities are in the interbank market are determined through matching algorithms.

Overview of the Model



The Banking Problem

- Banks have preferences with constant relative risk aversion. They maximize expected utility: $E[U(\pi_i)] = \frac{(E[\pi_i])^{1-\sigma}}{1-\sigma}$
- subject to the budget constraint:
  $c_i + pn_i + l_{i1} + l_{i2} + ... + l_{ik} = d_i + b_{i1} + b_{i2} + ... + b_{ik'} + e_i.$
- Profits depend on counterparty defaults and interest rates:
  $\pi_i = r_i^n \frac{n_i}{p} + r^l l_i - \frac{1}{1-\xi\delta_i} r^l b_i$
- When optimizing, banks take into account two stylized regulatory requirements:
  1. a liquidity requirement: $c_i \geq \alpha d_i$
  2. an equity requirement: $\frac{c_i + pn_i + l_i - d_i - b_i}{\omega_n pn_i + \omega_l l_i} \geq \eta$

E	expectations operator	$U(\cdot)$	utility function	i, j	bank identifiers
π	profit	c	cash holdings	p	price of non liquid asset
n	volume of non-liquid asset	e	equity	δ	default dummy
l_{ij}	amount lend	b_{ij}	amount borrowed	r^l	interbank interest rate
d	deposits	α	liquidity requirement	r^p	risk premium
η	equity requirement	ξ	loss given default	r^n	return on non liquid assets
ω_n	non-liquid asset risk weight	ω_l	interbank risk weight		

Interbank Market Clearing

The interbank market clears in two stages:

1. Price tatonnement in the interbank market.
   - banks choose, by maximizing their utility, their demand and supply of interbank debt.
   - A Walrasian auctioneer sums demand and supply of all agents and adjusts the interbank interest rate r^l until aggregate demand equals aggregate supply, i.e. $B = \sum_i b_i = L = \sum_i l_i$, with $b_i = \sum_j b_{ij}$ and $l_i = \sum_j l_{ij}$.
   - Note the interbank market is centralized with one interest rate.
2. Actual transactions are computed through a matching algorithm.
   - The matching relies on the concept of assortative matching developed by Becker (1973).
   - Banks are ordered according to the size of their trading positions.
   - Transactions are conducted for pairs of banks that want to lend or borrow similar amounts, respectively.
   - The procedure is repeated until all demand for interbank debt has been satisfied.

Market Clearing for Non-liquid Assets

Market clearing is modeled along the lines of Cifuentes et al. (2005). It operates once a shock has hit the system.

- Before the shock, the price is one ($p = 1$), which corresponds to zero aggregate sales when all agents are fully compliant with equity regulation.
- When the shock hits, banks will need to sell s_i assets in order to fulfill regulatory requirements.
- Cifuentes et al. (2005) have shown that after the shock a new equilibrium price is guaranteed under the following inverse demand function: $p = \exp(-\beta \sum_i s_i)$, with β being the price responsiveness with respect to non-liquid assets sold.

Systemic Risk Measures

- There are ex ante and ex post metrics for systemic risk.
  - Ex ante measures determine the contribution of a bank to systemic risk by considering its position in the network (degree, closeness, betweenness) prior to a shock.
  - Ex post measures consider the outcome of a shock (after simulation).
- Aldasoro et al. define their (ex post) measure of systemic risk as the ratio of assets of defaulting banks to total assets, i.e.

$$\Phi = \frac{\sum_{\Omega} \text{assets}_{\Omega}}{\sum_{i} \text{assets}_{i}},$$

  with Ω defining the set of defaulting banks.
- The (ex post) contribution of each individual bank to systemic risk is measured by the Shapley value.

The Shapley Value

- The Shapley value is a metric from the literature on cooperative and non-cooperative game theory:

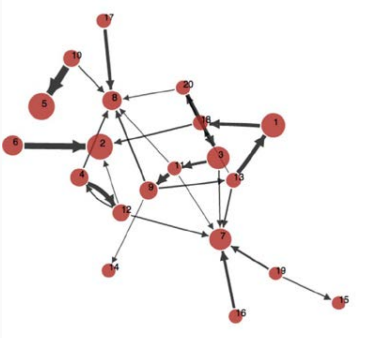
$$\Xi_i = \frac{1}{N!} \sum_{C \in C_N} \left(\Phi(C_{-i} \cup i) - \Phi(C_{-i}) \right)$$

- C denotes a coalition (group) of bank agents that are shocked and C_{-i} is that same coalition excluding bank i.
- C_N is defined as the set of all possible coalitions. If N is the number of banks in the model, there are $N! = 1 \times 2 \times 3 \times ... \times N$ coalitions in the set C_N.
- $\Phi(C_{-i} \cup i)$ is the ex post systemic risk metric when the coalition C including bank i is shocked. $\Phi(C_{-i})$ is the systemic risk when the coalition excluding bank i is shocked.
- The Shapley value gives the systemic risk contribution of bank i considering all potential shocks to the system.

Results

Baseline Network Structure

In the baseline network configuration there are 20 banks that have been calibrated to euro area data.



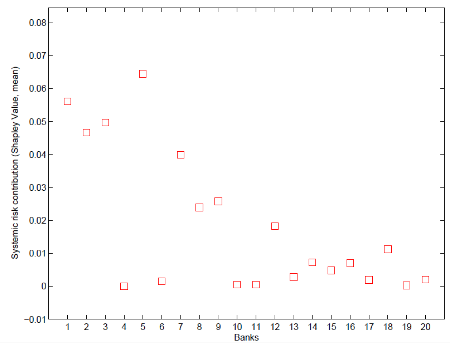
Density (%)	7.37
Average Degree	1.40
Average Path Length	2.60
Betweenness Centrality (Av.)	7.10
Eigenvector Centrality (Av.)	0.13
Clustering Coefficient (Av.)	0.03
Assortativity	
out-in degree	-0.15
in-out degree	0.26
out-out degree	-0.31
in-in degree	-0.44
# Intermediaries	9
# Core Banks	3
Interbank Assets/Total Assets (%)	23.68
Equilibrium Interbank Rate (%)	2.98

network representation

network characteristics

Systemic Risk Contribution

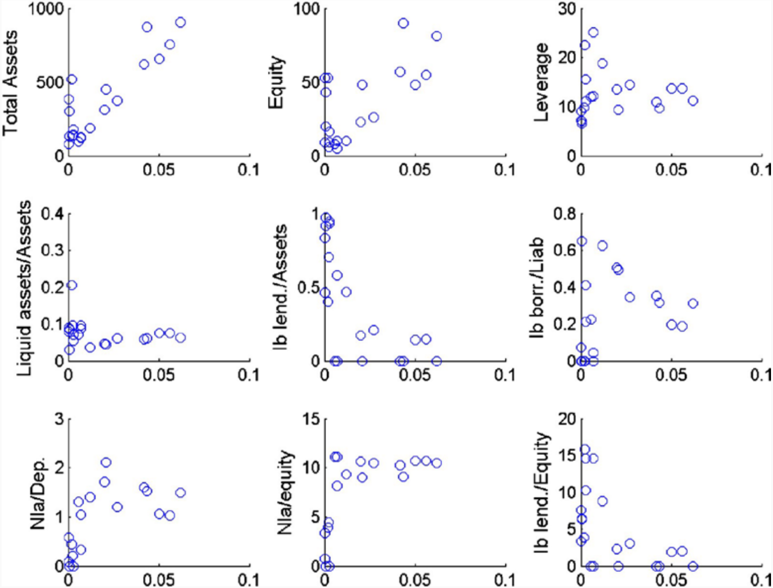
The contribution to systemic risk differs across banks:



High Shapley values pertain to banks which

- borrow to invest highly in non-liquid assets and
- are relatively large.

Shapley Value vs. Bank Characteristics

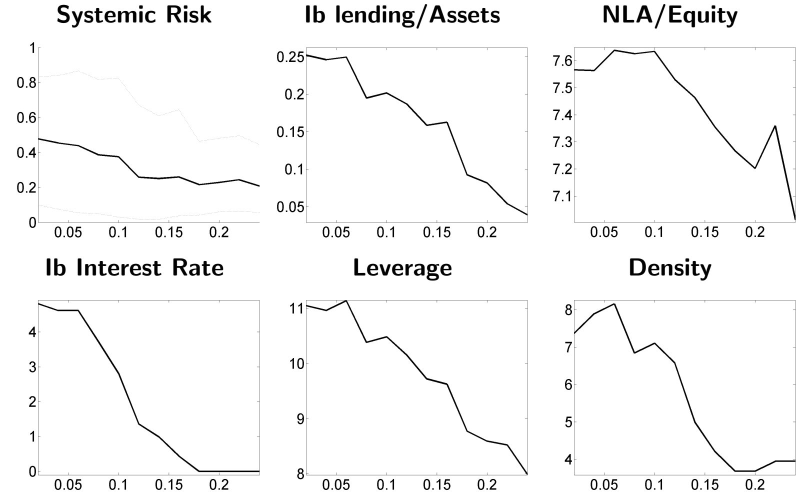


Explaining Systemic Risk Contribution

- Banks which borrow in the interbank market are the vehicle of shock propagation through direct network linkages (creditor/debtor relationships).
  - When a borrower bank defaults, losses are transmitted to the creditors.
  - The more a bank borrowed, the larger the likelihood of a default cascade in the bank network.
- Banks that invest in non-liquid assets are the vehicle of shock propagation through indirect linkages (overlapping portfolios).
  - A Bank investing in non-liquid assets will need to sell some of those assets when shocked.
  - The more a bank needs to sell to comply with regulation, the stronger the price effect and the higher the likelihood of a fire sale spiral occurring.
- Banks which borrow a lot and invest a lot are typically large banks in the model.

Changing Capital Requirements (1)

The effect of the equity requirement η on systemic risk, balance sheets and network characteristics.

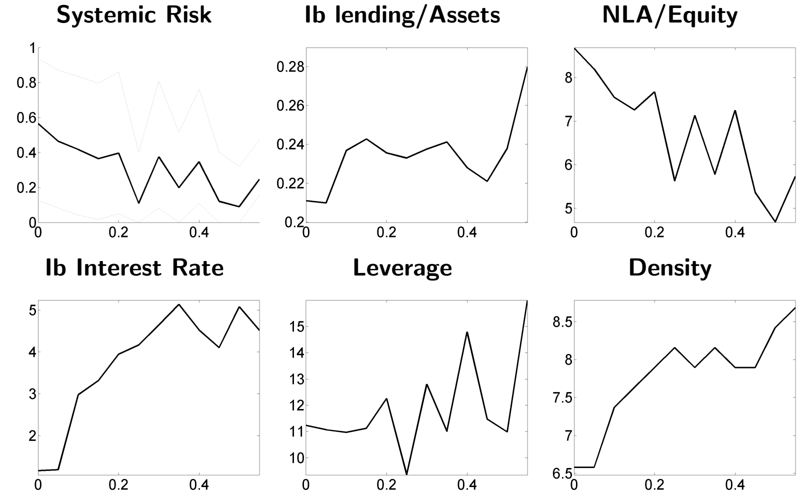


Changing Capital Requirements (2)

- Simulations of 1000 shocks imply that systemic risk is particularly responsive to equity requirements in the range of 0-13%, but relatively unresponsive for higher requirements.
- Higher equity requirements decrease leverage and interbank lending, which reduces interbank rates. Default cascades in the interbank market become less likely.
- Banks' investments in non-liquid assets (as a fraction of equity) is not strongly affected by higher equity requirements. The scope of fire sale spirals is therefore only slightly reduced.
- Overall: At least for low equity requirements systemic risk can be reduced without substantially impeding investments in non-liquid assets, which are a funding source for the real sector.

Changing Liquidity Requirements (1)

The effect of the liquidity requirement α on systemic risk, balance sheets and network characteristics.



Changing Liquidity Requirements (2)

- The effect of liquidity requirements on systemic risk becomes ambiguous for values above 0.2. Small changes to the requirement can have a large effect on systemic risk.
- Under tighter liquidity requirements, banks must hold more liquidity (cash) for precautionary reasons.
- Higher cash demand leads to an increased demand for interbank borrowing, while decreasing the demand for interbank lending. A higher interbank interest rate balances demand and supply.
- Non-liquid asset holdings decline as cash holdings increase. Higher liquidity requirements are thus detrimental to the supply of banks' real sector funding.
- As a result: systemic risk attributed to fire sales declines with lower holdings of non-liquid assets. Systemic risk attributed to direct interbank linkages increases slightly due to more interbank lending.

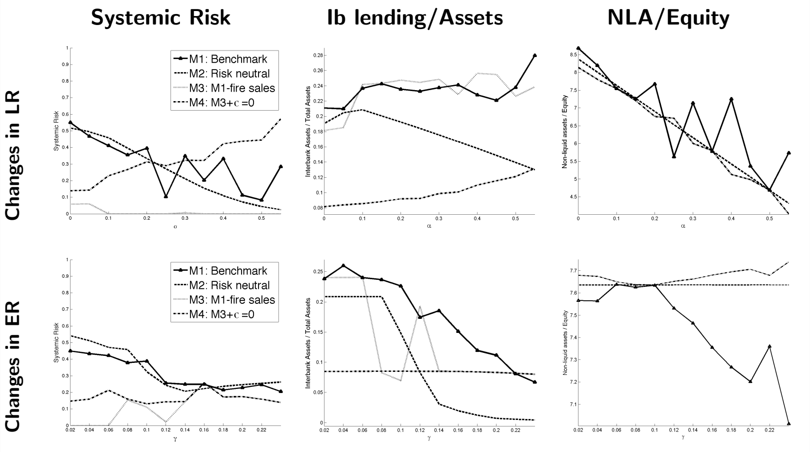
Isolating the Contagion Channels

Four different model setups are compared in order to isolate the impact of the individual contagion channels:

- **Model 1:** The benchmark model used for the preceding analysis. The model features risk averse banks and interaction of fire sale and network contagion channels.
- **Model 2:** Banks are risk neutral instead of risk averse. This implies that precautionary liquidity hoarding is no longer an issue.
- **Model 3:** The fire sale contagion channel is eliminated by making non-liquid asset holdings exogenous.
- **Model 4:** Keeps the setup of *Model 3*, but with risk-neutral banks.

Model Comparison (1)

How the impact of liquidity requirements (LR) and equity requirements (ER) change for different model setups.



Model Comparison (2)

Two interesting results are reported:

1. Due to higher non-linearities when all contagion channels interact and banks are risk averse, the benchmark model shows larger swings in the changes of systemic risk with respect to changes in liquidity and equity requirements.
2. When deactivating the fire sale contagion channel and banks are risk neutral (Model 4) systemic risk increases with increasing liquidity requirements. Higher demand for cash is satisfied by more interbank lending. Network linkages increase, which increases systemic risk via default cascades on the interbank market.

Conclusion

Conclusion

- A model of a banking network in which banks optimize their portfolios is developed.
- The banking network is employed to evaluate the effect of stylized liquidity and equity regulation on financial stability.
- Both liquidity and equity requirements reduce the systemic risk in the model.
- In contrast to equity regulation, liquidity regulation comes at the cost of banks' reduced investment in non-liquid assets. This can have negative repercussions on availability of funding to the real sector.