Bank Networks: Contagion, Systemic Risk & Prudential Policy

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Endogenous Financial Networks and Equilibrium Dynamics
Banque de France

Motivation

- Aftermath of crisis $\Longrightarrow$ channels of contagion
  - credit interconnections
  - overlapping portfolios / fire sales
  - liquidity hoarding
  - rollover risk / information coordination
- Interaction between channels
- Role of networks

Most importantly

- Quest for an “appropriate” regulatory framework
- Trade off: *efficiency* (maximize banks' investment in non-liquid risky assets) and *financial stability* (minimize systemic risk).

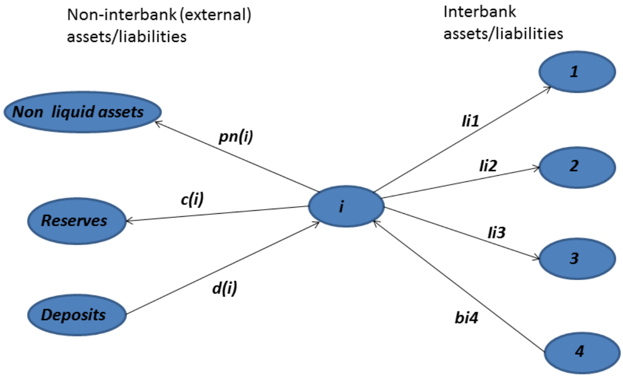
This paper

- Optimizing heterogeneous risk-averse banks, s.t. regulatory requirements
- Two endogenous price mechanisms
  - Interbank market (pre-shock)
  - Non-liquid assets market (post-shock)
- Interbank matching to replicate stylized facts about real world interbank networks
- Study effects of changes in prudential policy (evaluate trade-off)

Financial contagion

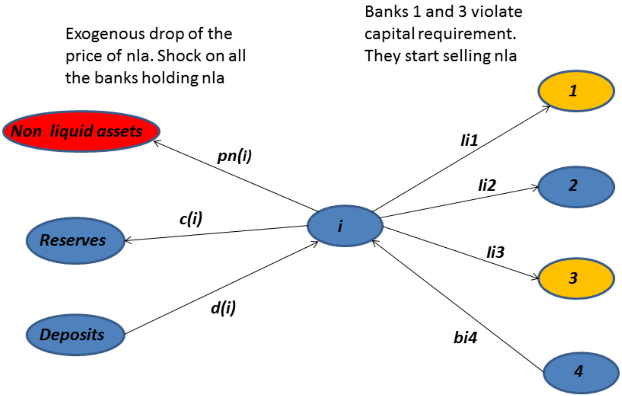
- Channels of financial contagion (risk transmission):
  1. *Credit interlinkages (network externalities)*
  2. *Fire sale of common non-liquid assets (pecuniary externalities)*
  3. *Liquidity hoarding*
- Systemic risk is due to the spreading of defaults through these channels.

The connections of bank i

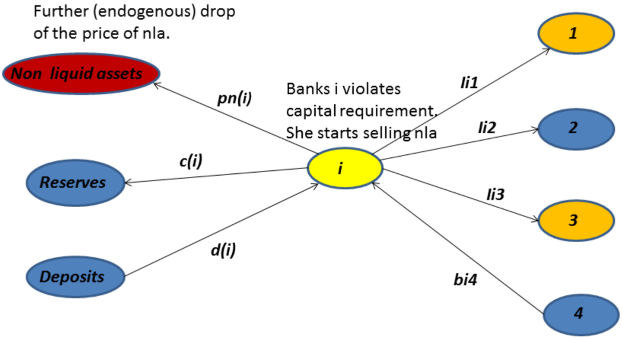


$$c_i + n_i p + \underbrace{l_{i1} + l_{i2} + \ldots + l_{iN}}_{\equiv l_i} = d_i + \underbrace{b_{i1} + b_{i2} + \ldots + b_{iN}}_{\equiv b_i} + e_i \qquad \text{(BSI)}$$

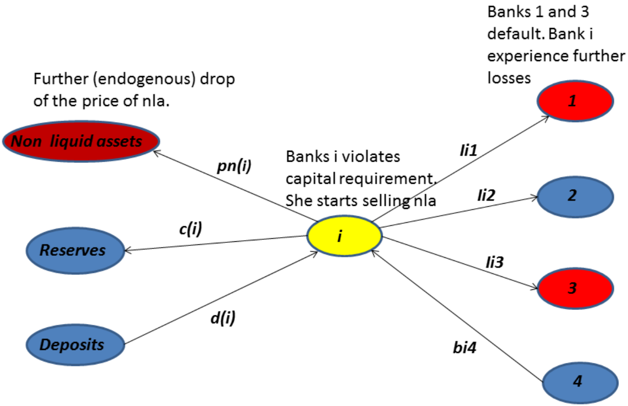
Shock to non-liquid assets $\Rightarrow \downarrow p$



Self-reinforcing downward pressure on price of nla



Collapse in mkt value of banks' assets might lead to default



Preview of main results

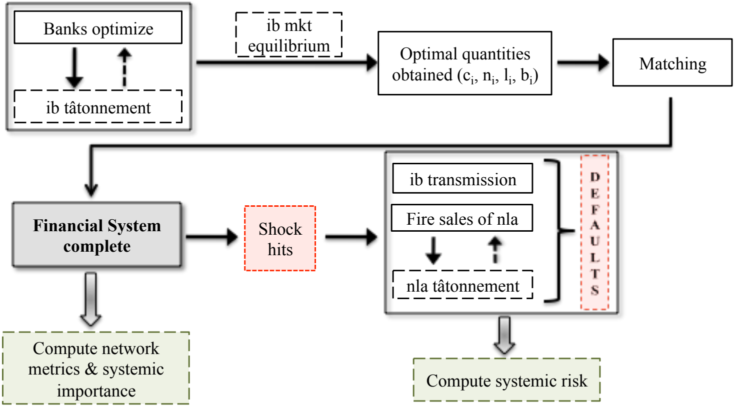
Simulation exercise

- *Systemic risk* (*S.R.*) not closely related to bal. sheet items (exc. TA)
- *S.R.* and *systemic importance* (*S.I.*) indicators do not deliver consistent message

Policy analysis

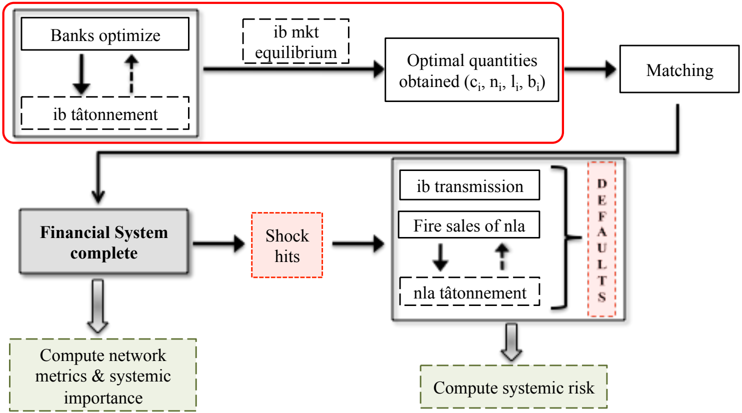
- Increasing the liquidity requirement reduces *systemic risk*, but with significant cost in terms of *efficiency*
- Increasing the equity requirement also reduces *systemic risk* (particularly over an initial range) without a considerable reduction in *efficiency*, but significantly reduces *interbank market activity*

A bird's eye view & related literature



A bird's eye view & related literature

Bluhm et al. '14, Halaj & Kok '14, Georg '13, Blasques et al. '15



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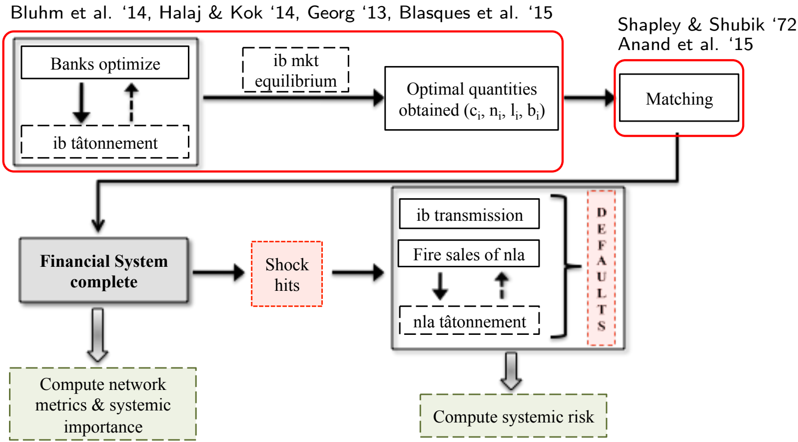

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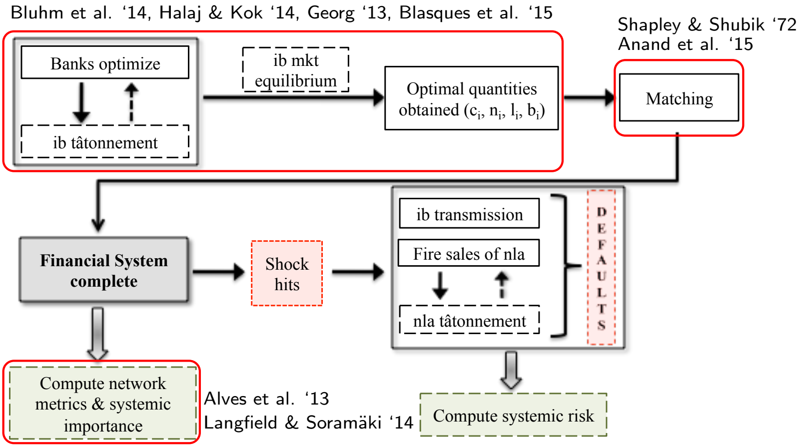

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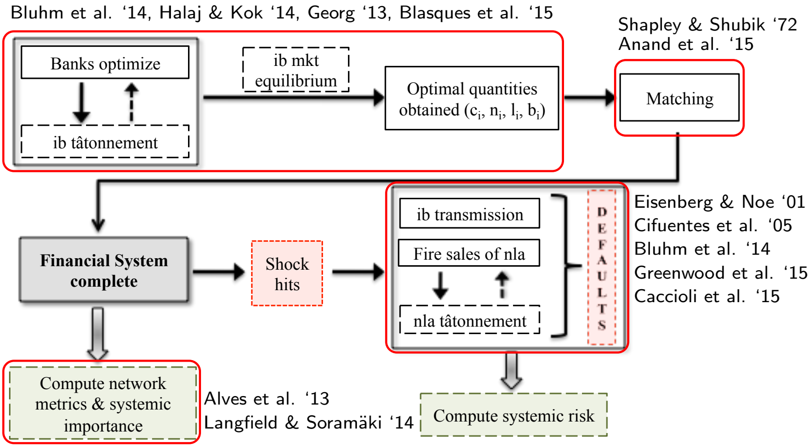

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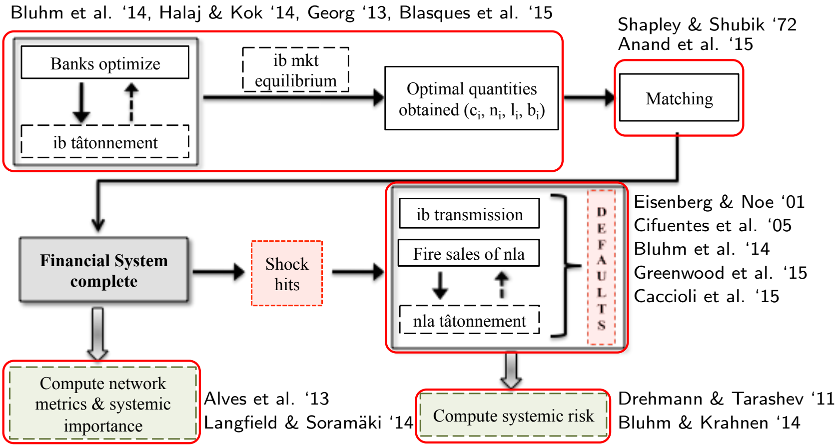

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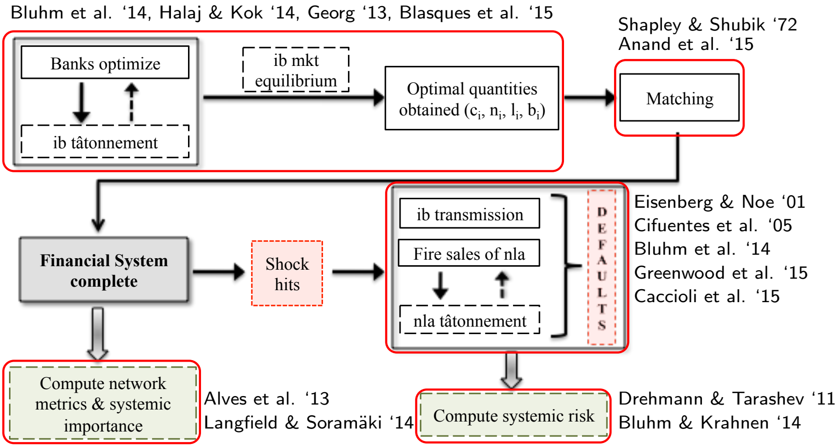


Important: banks choose *overall* exposure to network (Glasserman & Young '14)

The problem of the bank

- Banks' preferences: CRRA utility of profits $\Rightarrow U(\pi_i) = \frac{(\pi_i)^{1-\sigma}}{1-\sigma}$
- Choose c_i, n_i, l_i, b_i to maximize expected utility of profits (second order Taylor approximation around $E[\pi_i]$):

$$E\left[U(\pi)\right] \approx \frac{E[\pi]^{1-\sigma}}{1-\sigma} - \frac{\sigma}{2}E[\pi]^{-(1+\sigma)}\left(n_i^2\sigma^2_{r_i^n} - (b_i r^l)^2\xi^2(1-\xi E[pd_i])^{-4}\sigma^2_{pd_i}\right) \quad (1)$$

Profit

- Subject to (BSI), liquidity and equity requirements (+ n.n.c.)

$$c_i \geq \alpha d_i \quad \text{(LR)}$$

$$\frac{c_i + n_i p + l_i - d_i - b_i}{\omega_n p n_i + \omega_l l_i} \geq \gamma + \tau \quad \text{(ER)}$$

Tâtonnement on the interbank market

- Why? Demand and supply will not be mutually consistent after initial optimization (given starting value of r^l)
- Auctioneer evaluates *total* demand (B) and supply (L) of ib loans
- If $B > L$ ($B < L$) $\Longrightarrow \uparrow r^l$ ($\downarrow r^l$)
  $\rightarrow$ Let banks optimize again given the new r^l
  $\rightarrow$ continue until equilibrium is achieved
- We obtain two vectors $\mathbf{l} = [l_1, l_2, .., l_N]$ and $\mathbf{b} = [b_1, b_2, .., b_N]$ that are mutually consistent, such that $B = L$
- But ...*who is lending to whom and who is borrowing from whom?* (i.e. how does the *matrix of ib exposures* look like?)

Matching and the formation of the network

- To answer this we use a *Closest Matching (or minimum distance) Algorithm (CMA)*
  - Associates closest demand and supply
  - Order the vectors **l** and **b** in descending order
  - Assign transaction $x_{ij} = min\{l_i, b_j\}$
- The algorithm determines the *topology of the network.*
- By construction, CMA yields very low density

Life after a shock: *nla* mkt tâtonnement

- Pre-shock, $p = 1$
- Post-shock, supply and price of *nla* are affected
- Banks sell *nla* to fulfill ER
- $s_i'(p) < 0 \Longrightarrow s_n'(p) < 0$
- CFS inverse demand $\rightarrow p = exp(-\beta d_n)$
- Equilibrium $s_n = d_n$ $\rightarrow \Theta(p) = exp(-\beta s(p))$

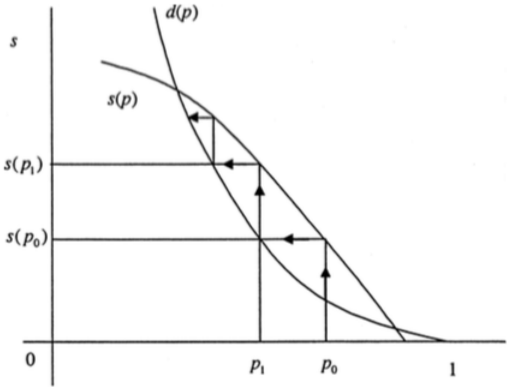


FIGURE 1. Amplification of shock through asset sales.
(Source: Cifuentes et al. (2005))

Systemic importance and systemic risk

- *Ex ante* measures of vulnerability: network centrality meaures (degree (in, out), closeness, betweenness, eigenvector)
- *Ex post* measure: ratio of the value of assets of defaulting banks (grouped in the set Ω) to total assets:

$$\Phi = \frac{\sum_{\Omega} assets_{\Omega}}{\sum_i asset_i}$$

- Contribution of each bank to systemic risk $\rightarrow$ *Shapley value*:

$$\Xi_i(v^{\Psi}) = \frac{1}{N!} \sum_{P \in \pi_N} \left(v^{\Psi}(\mathrm{Pre}_i(P) \cup i) - v^{\Psi}(\mathrm{Pre}_i(P)) \right)$$

- In practice approximated by taking k randomly sampled permutations:

$$\hat{\Xi}_i(v^{\Psi}) = \frac{1}{k} \sum_{P \in \pi_k} \left(v^{\Psi}(\mathrm{Pre}_i(P) \cup i) - v^{\Psi}(\mathrm{Pre}_i(P)) \right)$$

Baseline Calibration

Par./Var.	Description	Value
N	Number of banks in the system	20
α	Liquidity requirement ratio	0.10
ω_n	Risk weight on non-liquid assets	1
ω_l	Risk weight on interbank lending	0.20
γ	Equity requirement ratio	0.08
τ	Desired equity buffer	0.01
d_i	Bank deposits	Top20 EA
e_i	Bank equity	Top20 EA
σ	Bank risk aversion	2
ξ	Loss given default	0.5
$E[pd]$	Expected default probability	0.005
σ^2_{pd}	Variance of default probability	0.003
r_i^n	Return on non-liquid assets	$U(0, 0.15)$
$\sigma^2_{r_i^b}$	Variance of r_i^n	$\frac{1}{12}(\max(r_i^n) - \min(r_i^n))^2$
Ψ	Shocks to non-liquid assets	$\aleph(\mathbf{5}, 25 * \mathbf{I})$

Network metrics

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

Table 1 : Network characteristics - Baseline setting

Contribution to systemic risk

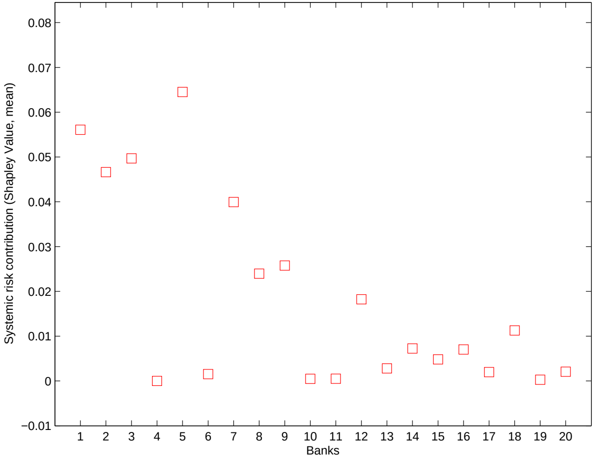
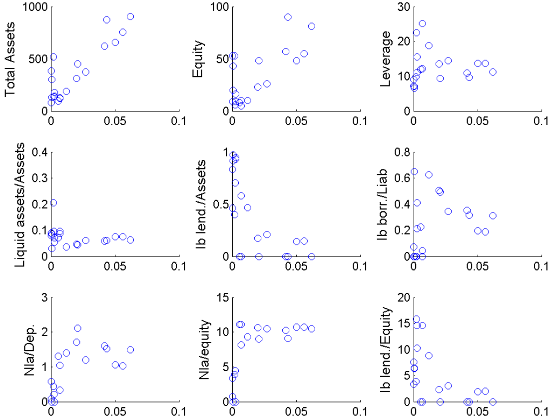
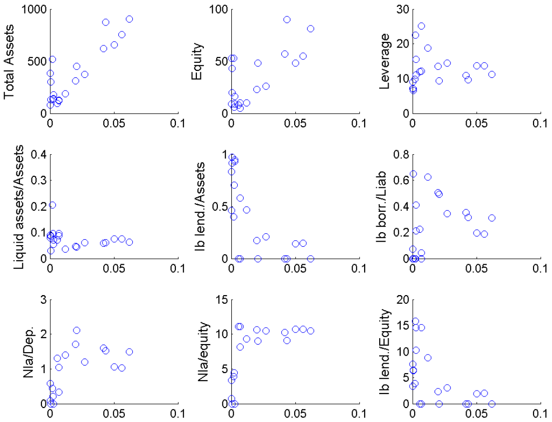


Figure 1 : Contribution to systemic risk (mean SV) by bank

Shapley value vs. bank characteristics



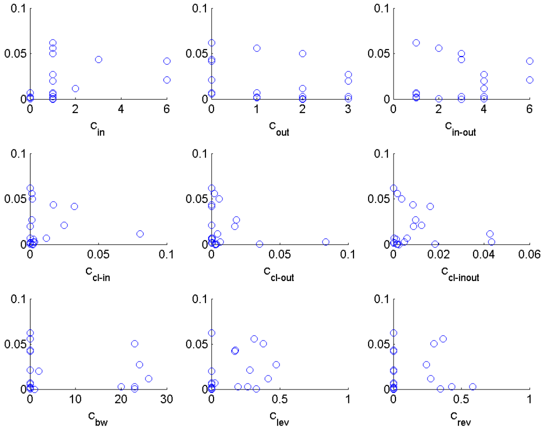
Shapley value vs. bank characteristics



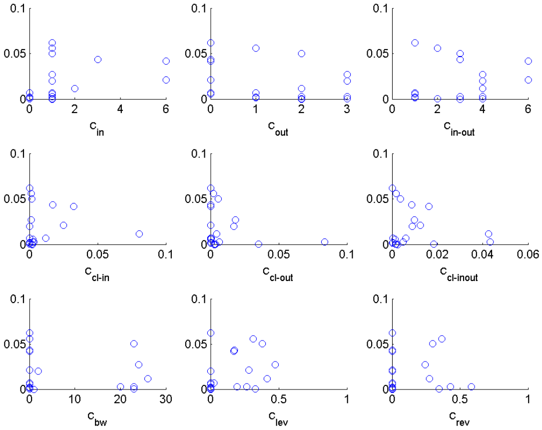
Strong relationship?

- A bit with total assets
- Not much with the rest ...

Shapley value vs. centrality measures



Shapley value vs. centrality measures



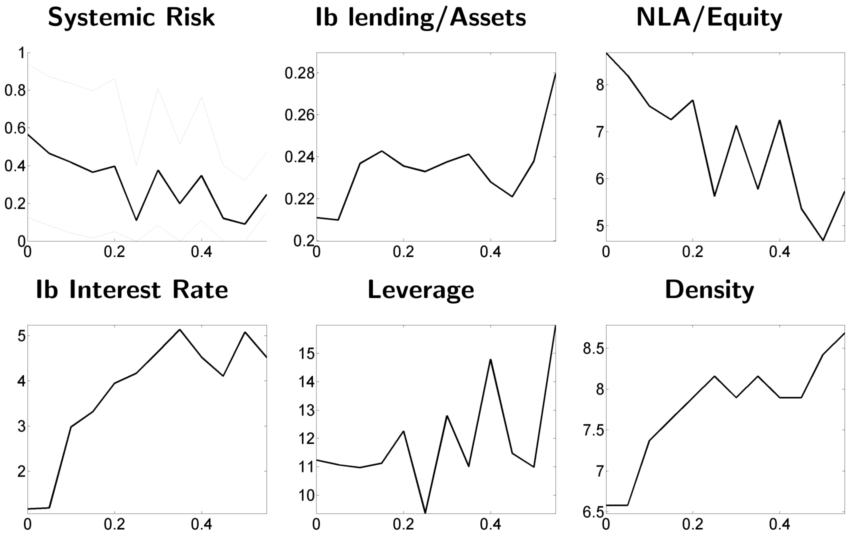
Consistent ranking?

- Not at all...

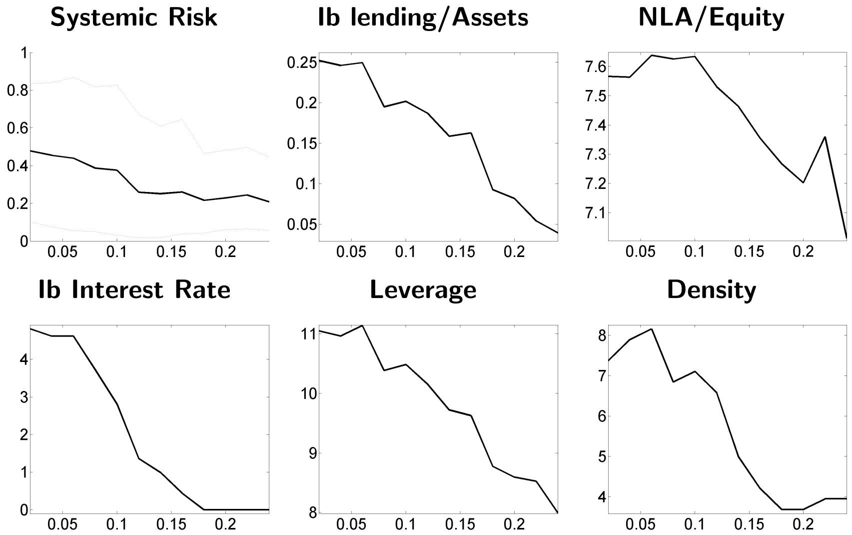
Bottom line

- Systemic risk and systemic importance indicators deliver different messages

Changes in the liquidity requirement (α)



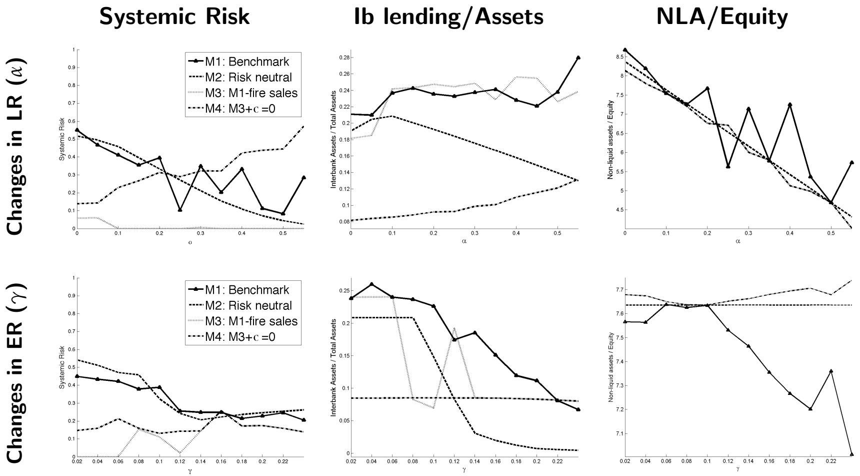
Changes in the equity requirement (γ)



Model Comparison

- **Model 1**: benchmark model (risk-averse banks, fire sales & network externalities)
- **Model 2**: risk neutral banks (linear objective function, i.e. $\sigma = 0$)
- **Model 3**: *Model 1* without fire sale channel (n_i no longer choice variable but calibrated to *Model 1* values, only network externalities)
- **Model 4**: *Model 3* without risk aversion ($\sigma = 0$)

Model Comparison - Results



Current extension

- Incorporate risk coming from the liability side
- News about a given banks health
  $\Longrightarrow$ might lead to deposit withdrawal if above a given threshold
  $\Longrightarrow$ information based runs: the sudden withdrawals of liquidity might force the bank, hit by the news shock, to fire-sale/default
- Interaction with other transmission channels
- Incorporation into banks' optimization problem
- Focus on liquidity regulation

THANK YOU!

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Obtaining the objective function

- Banks profit = return on ib lending **(A)** - cost of ib borrowing **(B)** + return on nla investment **(C)**
- **(A)** By lending l_{ij} to j, i expects to get

$$\underbrace{\left(1-pd_j\right)\left(r^l+r_j^p\right)l_{ij}}_{\text{with no default}}+\underbrace{pd_j\left(r^l+r_j^p\right)\left(1-\xi\right)l_{ij}}_{\text{with default}} \tag{2}$$

- Without the possibility of default, i gets the risk-free rate

$$l_{ij}r^l \tag{3}$$

- Equate 2 and 3 to solve for the fair risk premium charged to counterparty j:

$$r_j^p=\frac{\xi pd_j}{1-\xi pd_j}r^l \tag{4}$$

Back to bank problem.

Obtaining the objective function (cont.)

- Plugging the premium back into 2 and summing over all counterparties yields the expected return on interbank lending

$$l_i r^l \tag{5}$$

- **(B)** As a borrower bank, i must pay the premium associated to its own default probability; then cost of borrowing is:

$$r_i^b b_i = (r^l + r_i^p) b_i = \frac{1}{1 - \xi p d_i} r^l b_i \tag{6}$$

- **(C)** Gains from nla investment: $r_i^n \frac{n_i}{p}$

Back to bank problem.

Obtaining the objective function (cont.)

- Bank profits given by

$$\pi_i = r_i^n \frac{n_i}{p} + r^l l_i - \frac{1}{1 - \xi p d_i} r^l b_i \tag{7}$$

- Bank's preferences $\rightarrow$ CRRA utility function:

$$U(\pi_i) = \frac{(\pi_i)^{1-\sigma}}{1-\sigma} \tag{8}$$

- Second order Taylor approximation of 8 in the neighborhood of the expected value of profits $E[\pi_i]$ yields Eq. 1, with the variance of profits given by $\sigma_\pi^2 = \text{Var}\left(r_i^n n_i + r^l l_i - \frac{1}{1-\xi p d_i} r^l b_i\right) = \left(\frac{n_i}{p}\right)^2 \sigma_{r_i^n}^2 - (b_i r^l)^2 \text{Var}\left(\frac{1}{1-\xi p d_i}\right) + 2 n_i r^l b_i \text{cov}\left(r_i^n, \frac{1}{1-\xi p d_i}\right)$

Back to bank problem.