Systemic Risk and Stability in Financial Networks

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Motivation

Classical Theories of Banking (usually) study only one bank

Banks are connected in real life

The GFC revealed some banks are not only too big to fail ...

... but also too inter-connected to fail

Need to investigate the role of bank network structures ...

... and their interaction with financial structures

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“Interconnectedness”

A network is more inter-connected ...

... if one bank has higher debts with another bank

... if each bank borrows from/lends to more banks

NB: Different from “connectedness” in the network literature

Questions

How “inter-connectedness” affects bank failures?

Do banks fail more if their mutual debt levels high?

Do banks fail more if they borrow from/lend to more banks?

This paper (and the next)

Model N banks with with long-term assets y, short-term liquidity risk L

Assumption 1: Pledgeability is limited

Can't borrow against full asset value to meet liquidity shock

Assumption 2: Liquidity shocks are non-contractable

Cannot pay premium for contingent insurance to shock

Assumption 3a: Financial networks are short-term debts

Interbank debts mature when the liquidity shocks occur

Typical Network Structures

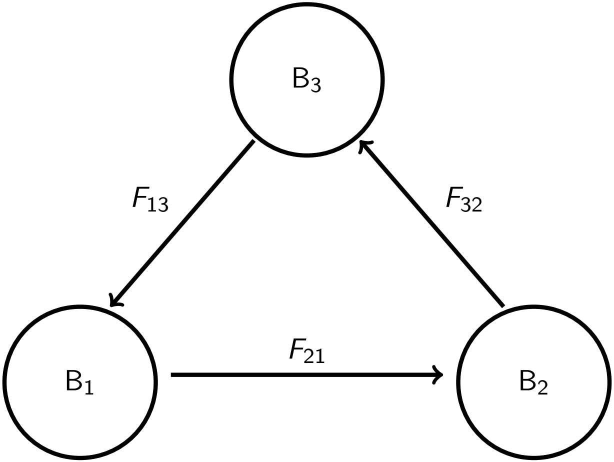

Figure: Ring Network (RN)

Typical Network Structures

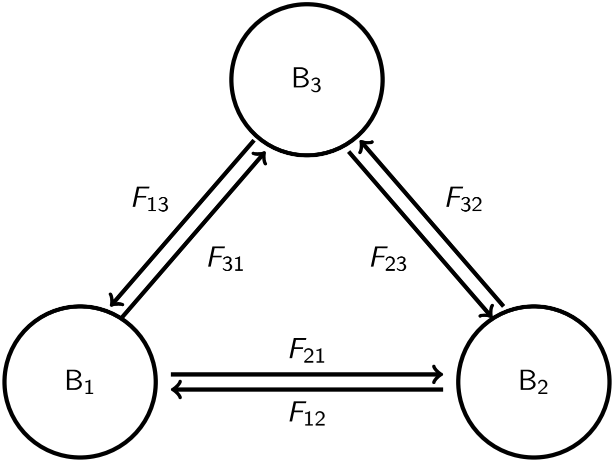

Figure: Complete Network (CN)

Key Results

R1: Higher debt levels lead to liquidation cascade

R2: Phase transition

Complete network most stable with small shocks

Complete network least stable with large shocks

The Model

Date 0:

> Bank j with existing short-term interbank debts of total face value F_j

Date 1:

> M liquidity shocks are realized and interbank debts mature
> Banks receive payment from/repay other banks
> Banks borrow at most θy from the market
> Bank are liquidated if they cannot repay in full

Date 2:

> Asset y is realized if not liquidated

Default and Liquidation

When a bank defaults on any liabilities

A fraction $(1-\theta)y$ is liquidated

The rest θy is realized and paid out

The liquidated bank cannot borrow senior

Liquidation Rule

Bank j has two types of obligations

1. Liquidity shock $L_j \in \{0, L\}$, which is senior (e.g. deposits)
2. Liabilities to other banks F_j

And he has two sources of liquidity

1. Payment from other banks X^j
2. Additional θy, from borrowing or liquidation

Thus, bank j is liquidated if

$$X^j + \theta y \leq L_j + F_j$$

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Payment to Other Banks

Let X_j be the payment of bank j to other banks

When $X^j + \theta y \geq L_j + F_j$, no default

$$X_j = F_j$$

When $X^j + \theta y \leq L_j$, full default on the interbank debts

$$X_j = 0$$

When $L_j + F_j \geq X^j + \theta y \geq L_j$, partial default on the interbank debts

$$X_j = X^j + \theta y - L_j$$

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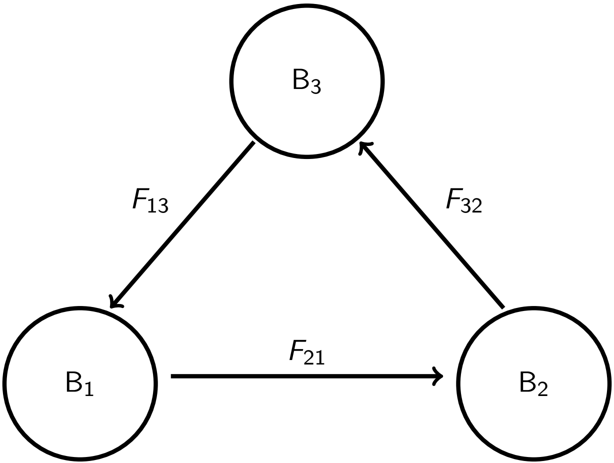
$$X_j = X^j + \theta y - L_j$$

where network kicks in

R1: Higher debt levels lead to more liquidation

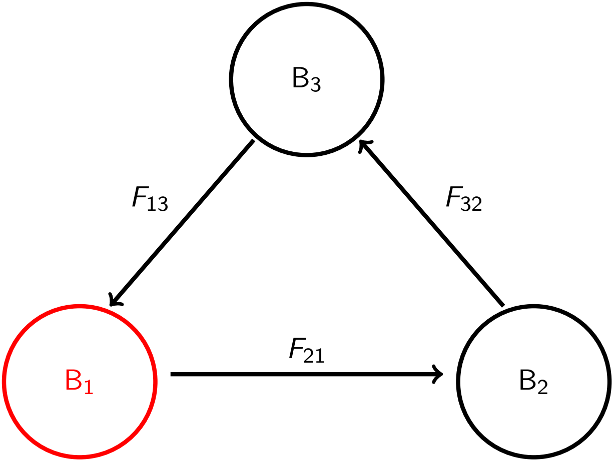
An Example of Ring Network with Three Banks

Zero-net-positions $F_{ij} = F$



An Example of Ring Network with Three Banks

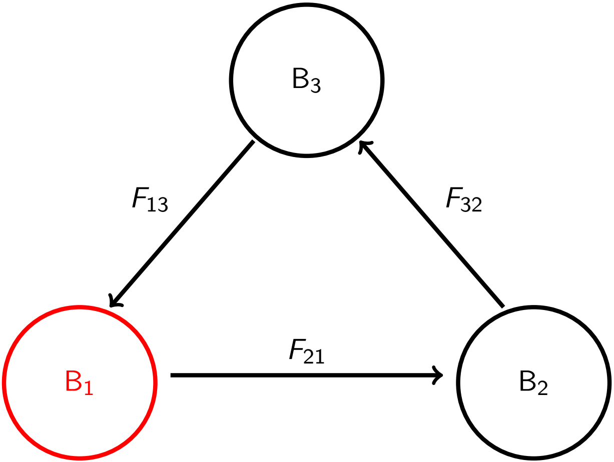
One bank is shocked with $L = 2.5\theta y$



An Example of Ring Network with Three Banks

We will show

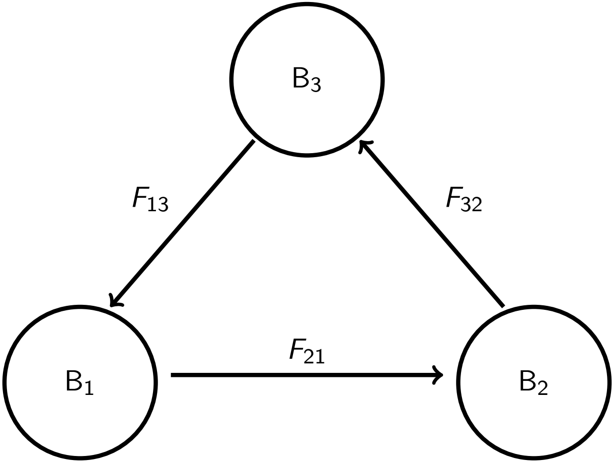
- One bank is liquidated when F is small ($F = \theta y$)
- Two banks are liquidated when F is large ($F = 2\theta y$)



R1a: One Bank Liquidated if Debts Low

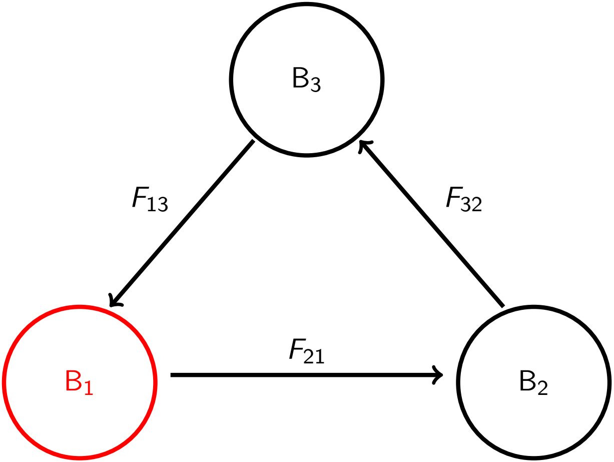
Result 1a: One Bank Liquidated if $F = \theta y$

A ring network with 3 banks



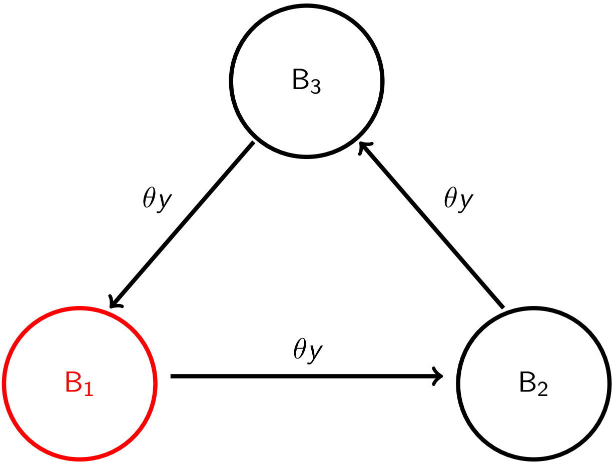
Result 1a: One Bank Liquidated if $F = \theta y$

Bank 1 is shocked with $L = 2.5\theta y$



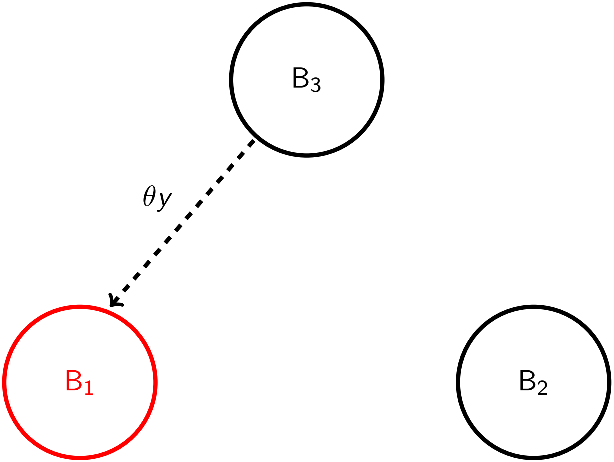
Result 1a: One Bank Liquidated if $F = \theta y$

Suppose the face values are $F_{ij} = \theta y$



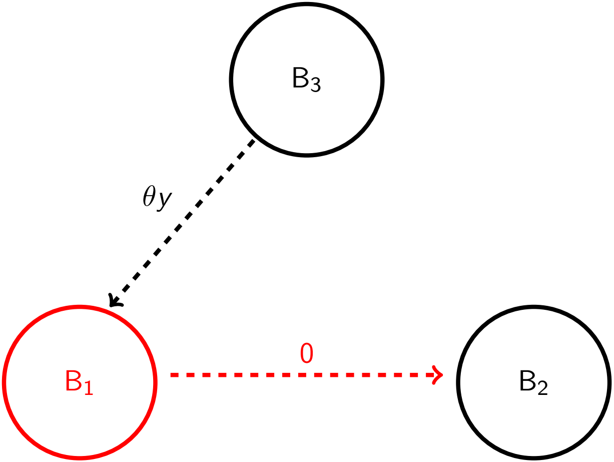
Result 1a: One Bank Liquidated if $F = \theta y$

Bank 1 is liquidated because $\theta y + \theta y < L + \theta y$



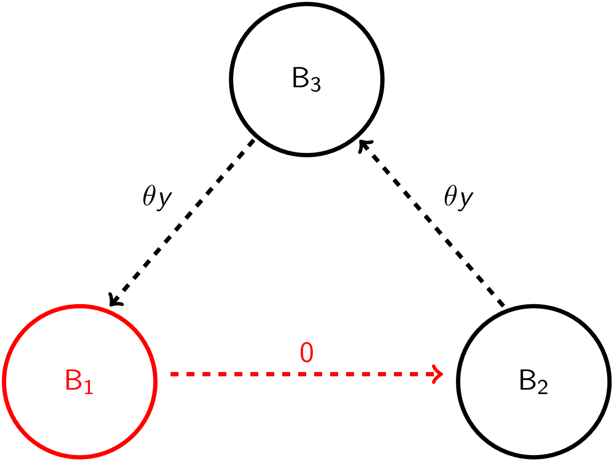
Result 1a: One Bank Liquidated if $F = \theta y$

Bank 1 pays out 0



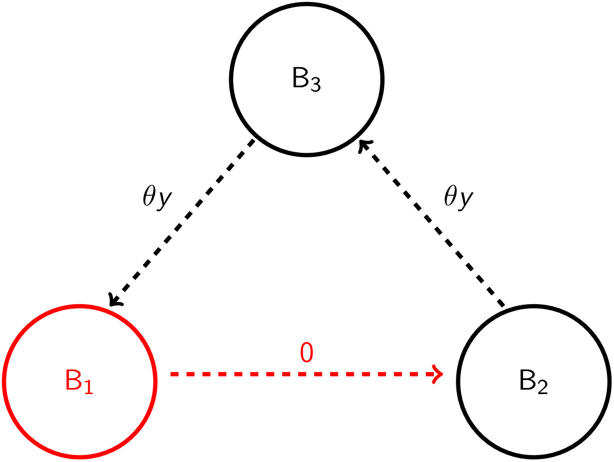
Result 1a: One Bank Liquidated if $F = \theta y$

Bank 2 does not default $\theta y \leq \theta y$



Result 1a: One Bank Liquidated if $F = \theta y$

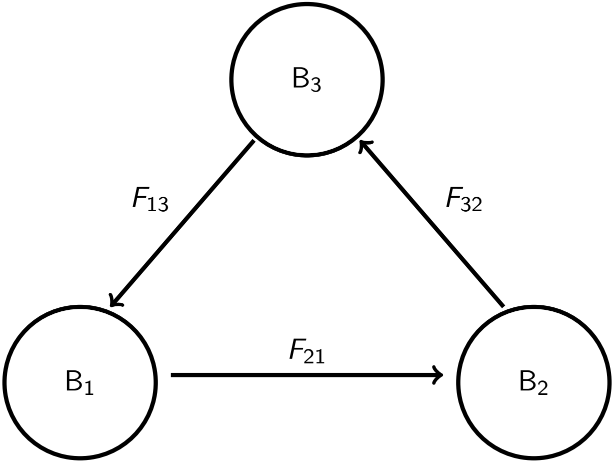
Verify Bank 3 does not default



R1b: Two Banks Liquidated if Debts High

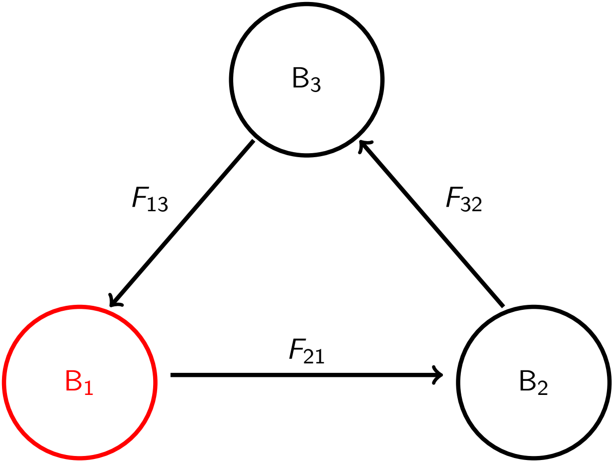
Result 1b: Two Banks Liquidated if $F = 2\theta y$

A ring network.



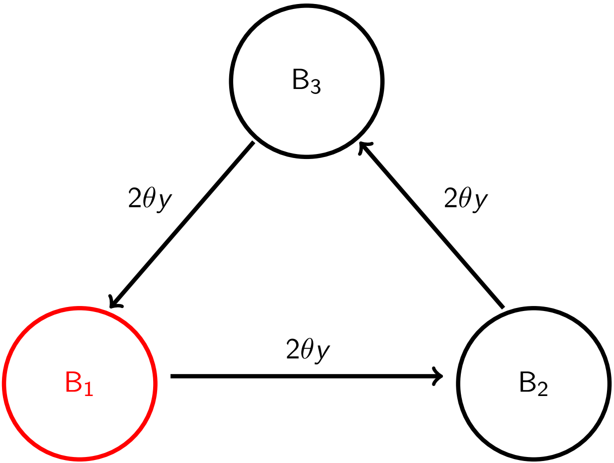
Result 1b: Two Banks Liquidated if $F = 2\theta y$

Bank 1 is shocked with $L = 2.5\theta y$



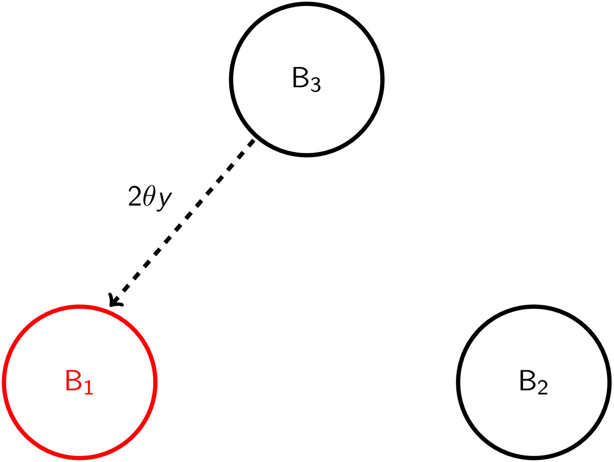
Result 1b: Two Banks Liquidated if $F = 2\theta y$

Suppose now the face values are $F_{ij} = 2\theta y$



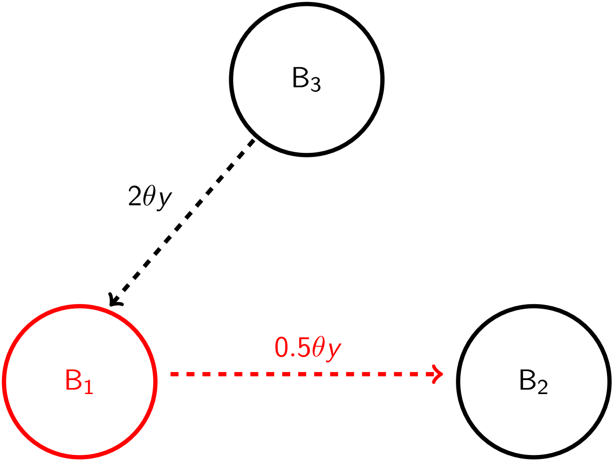
Result 1b: Two Banks Liquidated if $F = 2\theta y$

Suppose bank 3 does not default



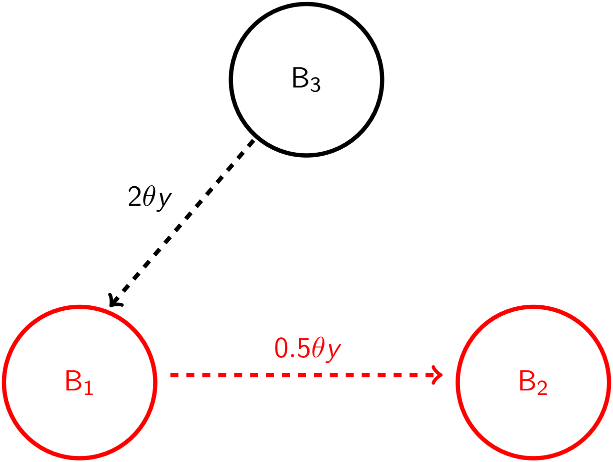
Result 1b: Two Banks Liquidated if $F = 2\theta y$

Bank 1 defaults and pays out $2\theta y + \theta y - 2.5\theta y = 0.5\theta y$



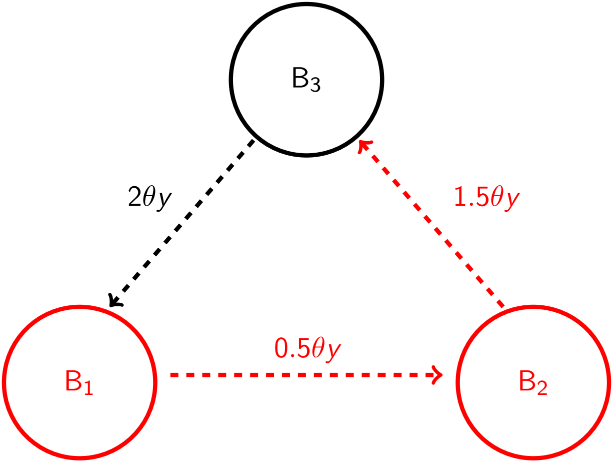
Result 1b: Two Banks Liquidated if $F = 2\theta y$

Since $0.5\theta y + \theta y < 2\theta y$, Bank 2 defaults ...



Result 1b: Two Banks Liquidated if $F = 2\theta y$

... and pays out $0.5\theta y + \theta y = 1.5\theta y$



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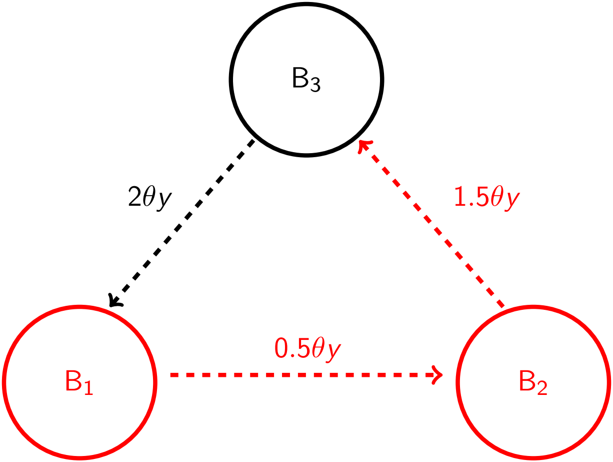


Intuition

Why higher debts lead to more liquidation?

A not-shocked bank is liquidated if the counter-party risk exceeds θy

$$\underbrace{F^j}_{\text{what other banks owe you}} - \underbrace{X^j}_{\text{what they actually pay you}} \geq \theta y$$

High debt levels allow transmission of greater counter-party risk

Transmitted θy when $F = \theta y$

Transmitted $1.5\theta y$ when $F = 2\theta y$

Debt level is an upper bound of largest possible counter-party risk

$$F^j - X^j \leq F^j$$

Result 2: Phase Transition

Roadmap

We will show that

R2a: Only one bank is liquidated with a small shock

Shocks that can be absorbed by the system $ML < N\theta y$

R2b: Only one bank is liquidated with a small shock and more debts

Show R2c is not driven by more debts (not result 1)

R2c: Two banks are liquidated with large small shock

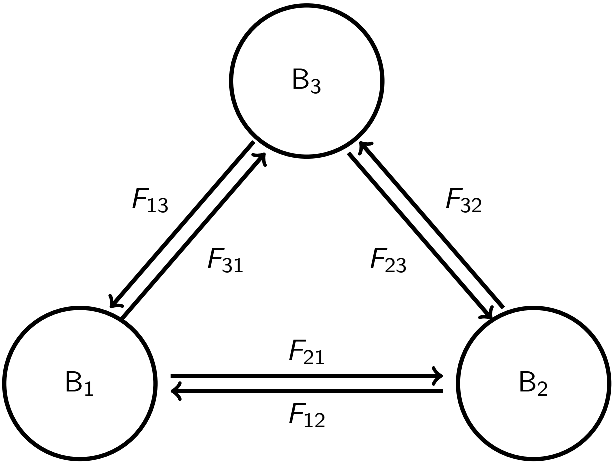
Complete network achieves the lower/upper bound of # bank failures

Show it's indeed the most/least stable network

Result 2a: Complete Network Most Stable when Shocks Small

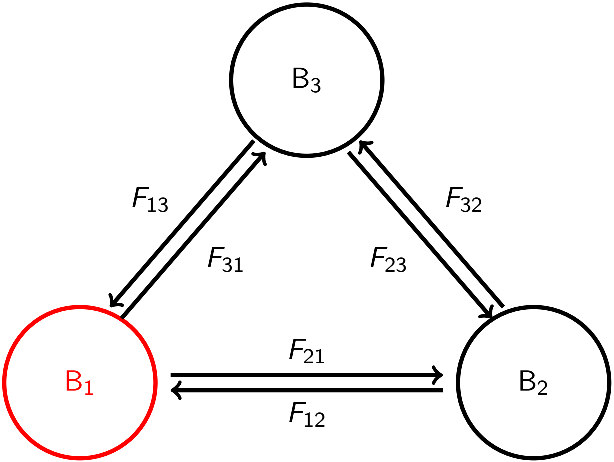
R2a: Complete Network Most Stable when Shocks Small

The banks, $L = 2.5\theta y$, $F = 2\theta y$ but $F_{ij} = \theta y$



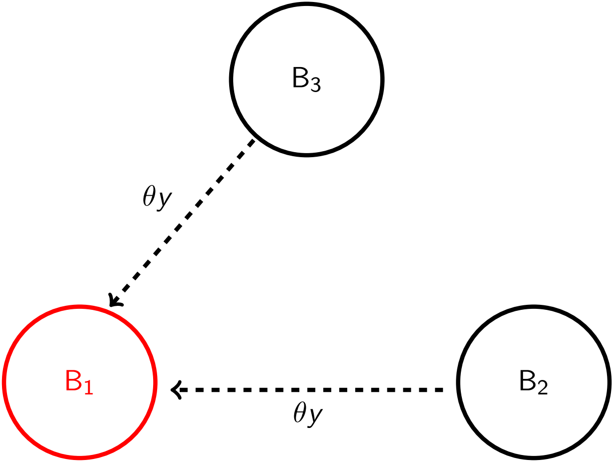
R2a: Complete Network Most Stable when Shocks Small

Bank 1 is shocked again (Sorry, Bank 1!)



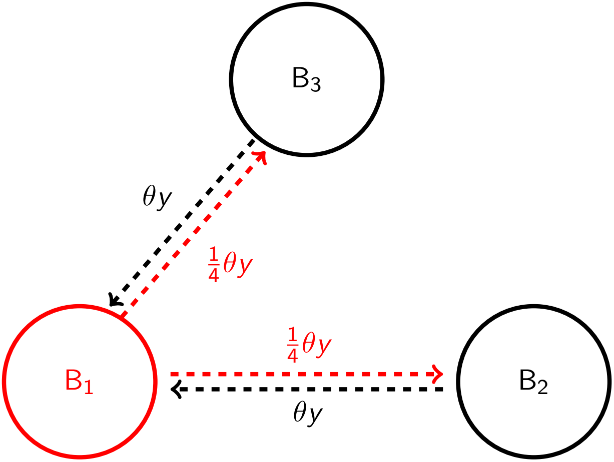
R2a: Complete Network Most Stable when Shocks Small

Suppose bank 2 and 3 do not default



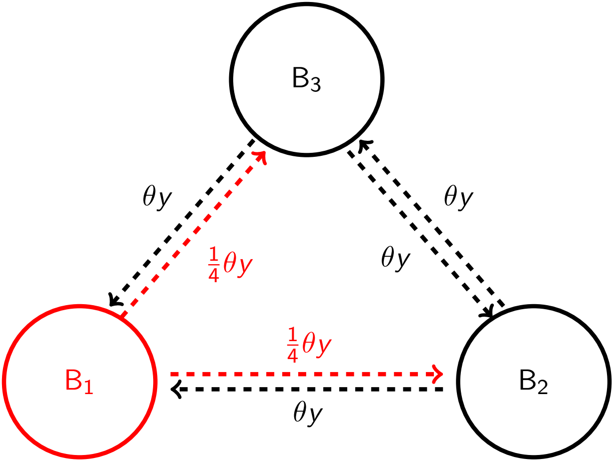
R2a: Complete Network Most Stable when Shocks Small

Bank 1 pays out $2\theta y + \theta y - 2.5\theta y = 0.5\theta y$



R2a: Complete Network Most Stable when Shocks Small

Verify bank 2 and 3 don't default.



Intuition

With small shocks, connected networks diversify the liquidity risk

The default of shocked bank is borne by two banks, each only a half

$1.5\theta y$ in the ring network but $0.75\theta y$ in the complete network.

Bank 2 also receives payment from not-shocked bank

θy in the ring network but 0 in the complete network.

R2b: One Bank Liquidated with Higher Debt Level

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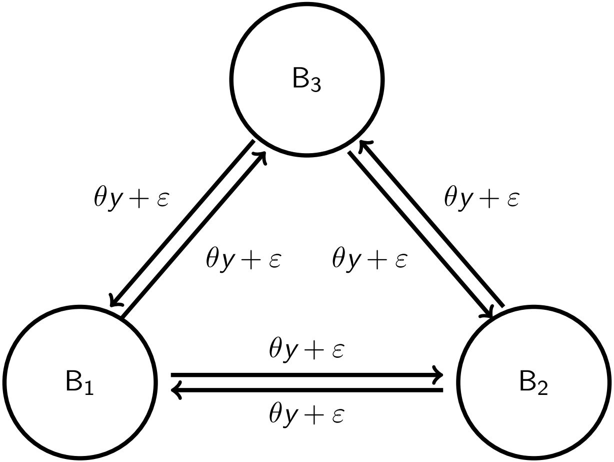
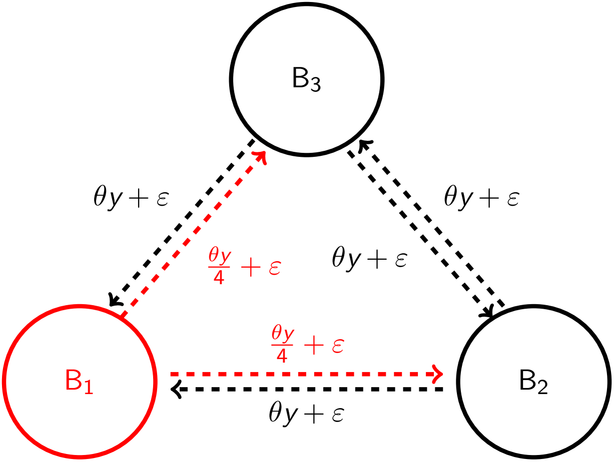
Suppose the face value of each bank's liability increases by 2ε



R2b: One Bank Liquidated with Higher Debt Level

Equilibrium: The payment is also increased by 2ε



Intuition

The liquidity shock is completely absorbed

- The shocked bank absorbs θy
- Each not-shocked bank absorbs $\frac{3\theta y}{4}$

Small shocks can be absorbed by all banks, without full liquidation

Complete network ensures enough diversification

Liquidity shock fully transmitted when F small

- No more transmission of liquidity shock with higher debt level

R2c: Complete Network Least Stable when Shocks Large

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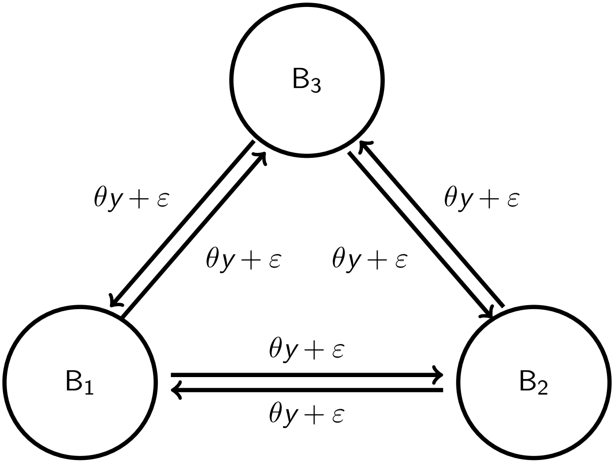
Again, 3 banks, $F = 2\theta y + 2\varepsilon$ but $L = 3.5\theta y$. ($0 < 2\varepsilon < 0.5\theta y$)



R2c: Complete Network Least Stable when Shocks Large

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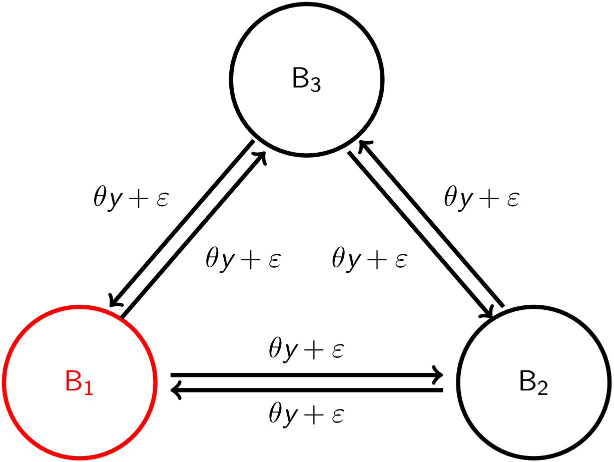

R2c: Complete Network Least Stable when Shocks Large

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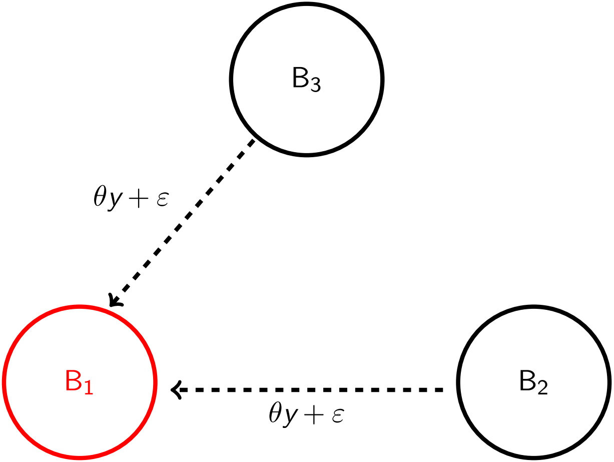
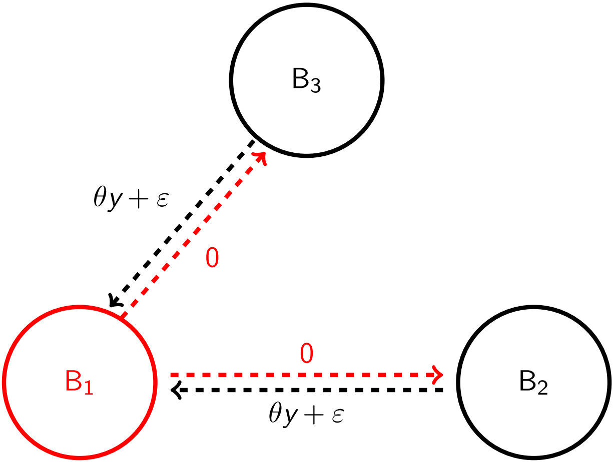


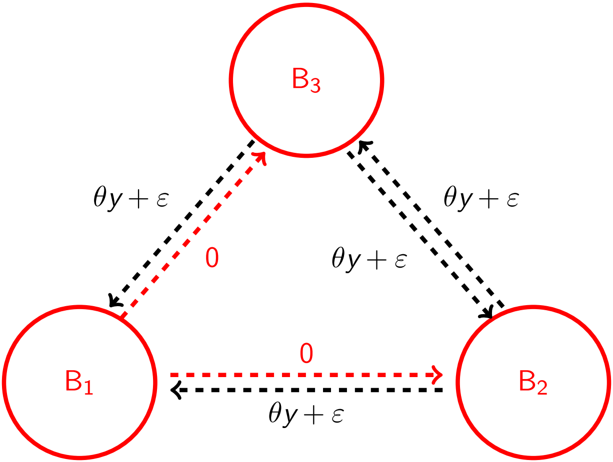
R2c: Complete Network Least Stable when Shocks Large

Bank 1 pays out $\max\{2\theta y + 2\varepsilon + \theta y - L, 0\} = 0$



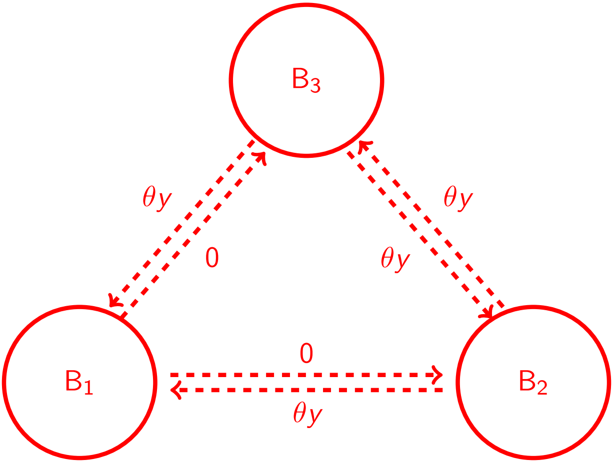
R2c: Complete Network Least Stable when Shocks Large

Bank 2 and 3 have to be liquidated! $(\theta y + \varepsilon) + \theta y < 2(\theta y + \varepsilon)$



R2c: Complete Network Least Stable when Shocks Large

Actual equilibrium payment (for any $\varepsilon > 0$)



Intuition

Larger shock cannot be absorbed even by all firms

Full liquidation if liquidity risk spread out

Better to concentrate liquidity within the shocked banks

Number of Liquidated banks

With ST network, (we will prove) the number of liquidated banks $|\mathcal{D}|$ is

$$M \leq |\mathcal{D}| \leq \frac{ML}{\theta y}$$

All shocked banks at least default on the junior debt

A not-shocked bank is liquidated if counter-party risk exceeds θy

Implication:

Complete Network is the most stable network when shocks small attaining the lower bound

Complete Network is the least stable network when shocks large attaining the upper bound

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Proof of the Upper Bound

If bank j defaults on F_j but not L_j

$$X^j + \theta y = X_j + L_j$$

If bank i defaults on L_i (and hence all of F_i)

$$X^i + \theta y < \underbrace{X_i}_{=0} + L_i$$

Let $\mathcal{D}$ be the defaulting banks

$$\sum_{i \in \mathcal{D}} X^i + |\mathcal{D}|\theta y < \sum_{i \in \mathcal{D}} X_i + ML$$

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$$\sum_{i \in \mathcal{D}} X^i + |\mathcal{D}| \theta y < \sum_{i \in \mathcal{D}} X_i + ML$$

The rest banks $k \notin \mathcal{D}$ do not default $X^k = X_k$

$$\sum_{i \in \mathcal{D}} X^i = \sum_{i \in \mathcal{D}} X_i$$

Proof of the Upper Bound

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Let $\mathcal{D}$ be the defaulting banks

$$\sum_{i \in \mathcal{D}} X^i + |\mathcal{D}|\theta y < \sum_{i \in \mathcal{D}} X_i + ML$$

We obtain the upper bound

$$|\mathcal{D}| < \frac{ML}{\theta y}$$

Can we avoid the liquidation cascade?

Yes, we can net out the interbank debts

- It can be netted out ex ante
  - Mutual liabilities are netted out before liquidity shocks occur
  - Equivalent to a null network if no net positions
- It can be netted out ex post
  - Mutual liabilities are netted out when one party defaults
  - Equivalent to a complete network with lower face value

(Ex ante) Netting is good in AOT

At most M banks are liquidated, without a short-term debt network

At least M banks are liquidated, with a short-term debt network

Suggesting (ex ante) netting is good

- Null network achieves the lower bound

(Ex post) Close-Out Netting is also good in AOT

The liquidation of a not-shocked bank is caused by default of shock banks

Bank i and bank j owe F to each other

Bank i repays only $X < F$ to bank j

Bank j's liability to bank i is also reduced to X

Net-liability of a not-shocked bank is zero, no liquidation.

NB1: Close-out netting changes priority structure, sparking policy debate

NB2: Close-out netting not always working (Recall ring network)

Netting

Jason R. Donaldson, Giorgia Piacentino, Xiaobo Yu

Motivation

Banks have huge gross positions

E.g. HSBC's net position $|£24\text{B} - £21.5\text{B}| \approx 10\%$ gross

Previous analysis (AOT) shows

Off-setting debts amplify financial risk

Netting mitigate risk transmission

Why not net them out?

Note, these gross positions are not *short-term*!

Average maturity more than a year

Unaccounted by the AOT Model with short-term debt network

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Question

How are long-term debt networks different?

Does higher face value exacerbate financial fragility?

Does borrowing from/lending to more banks lead to more liquidation?

This paper

Model N banks with with long-term assets y, short-term liquidity risk L

Assumption 1: Pledgeability is limited

Can't borrow against full asset value to meet liquidity shock

Assumption 2: Liquidity shocks are non-contractable

Cannot pay premium for contingent insurance to shock

Assumption 3b: Financial networks are long-term debts

Interbank debts mature when the assets mature

Key Results

R3: Higher Debt Level leads to Less Liquidation

R4: Phase transition

Complete network most stable with small shocks

Complete network least stable with large shocks

Opposite Results

With short-term networks, high debt level leads to more liquidation

- More risks are transmitted to healthy banks

With long-term networks, high debt level leads to less liquidation

- Shocked banks can dilute not-shocked banks more

Same Result but Different Mechanisms

In both models

- Complete network most stable when shocks small
  - ST network diversifies the risk
  - LT network provides sufficient dilution
- Complete network least stable when shocks large
  - ST network transmitted too much risks
  - LT network cannot provide enough dilution

The Model

Date 0:

> Bank j with existing long-term interbank debts of total face value F_j

Date 1:

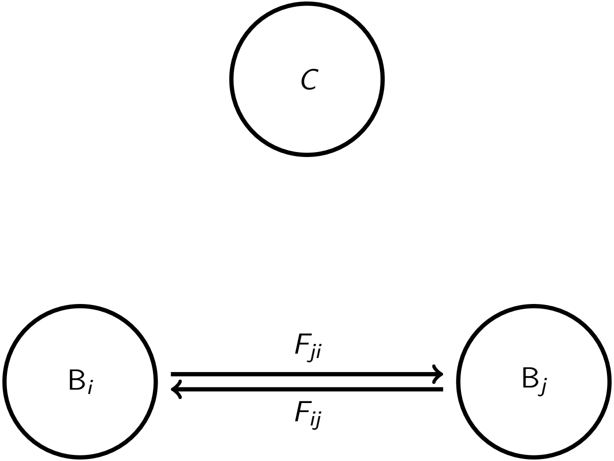
> M Liquidity shocks are realized
> Banks sell their claims to the competitive market C
> Banks borrow at most θy from the market, diluting the other banks
> Bank are liquidated if they cannot satisfy the liquidity needs

Date 2:

> Asset y is realized if not liquidated
> Banks decide to default or not

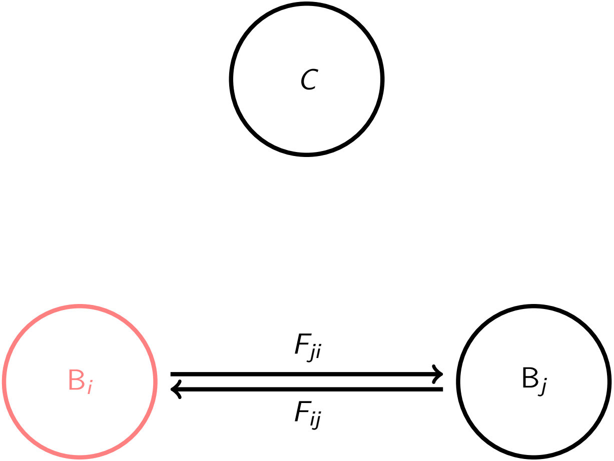
Graph Illustration

Two banks with mutual liabilities



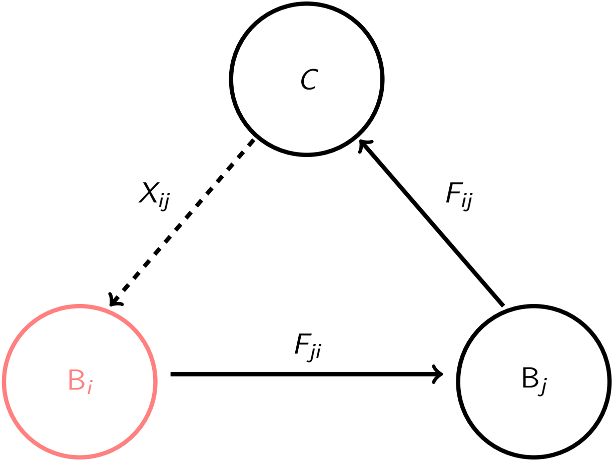
Graph Illustration

Bank i is shocked



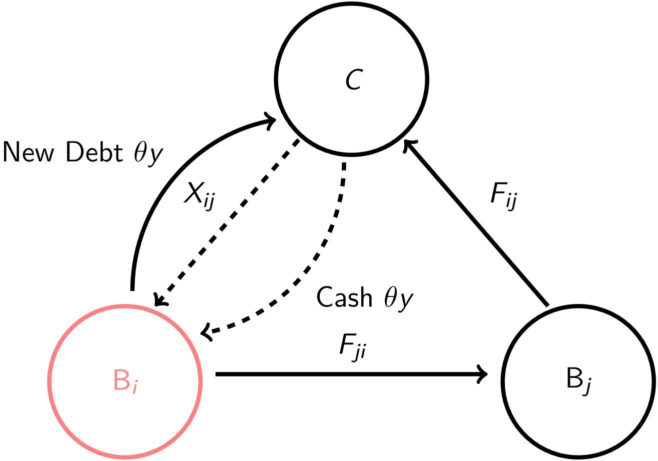
Graph Illustration

Bank i sells claims to the market

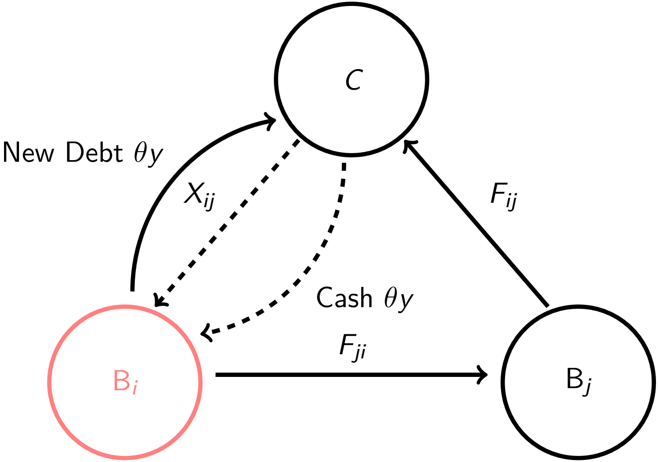


Graph Illustration

Bank i issues new senior debt



Graph Illustration



No liquidation if $X_{ij} + \theta y \geq L$

Liquidation and Default

Let X^j be the amount each bank receives from selling the claims

A shocked bank is liquidated if and only if

$$X^j + \theta y < L$$

A not-shocked bank is never liquidated.

A bank can default and divert $(1-\theta)y$. But when?

New senior debt repaid in full

Default more profitable when

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$$y + X^j - \underbrace{(F_j + L_j)}_{\text{repay in full}} < (1-\theta)y$$

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Default more profitable when

$$\underbrace{X^j + \theta y - L_j}_{\text{Default Payment } X_j} < F_j$$

Two ways to raise Liquidity

A shocked bank can raise liquidity in two ways

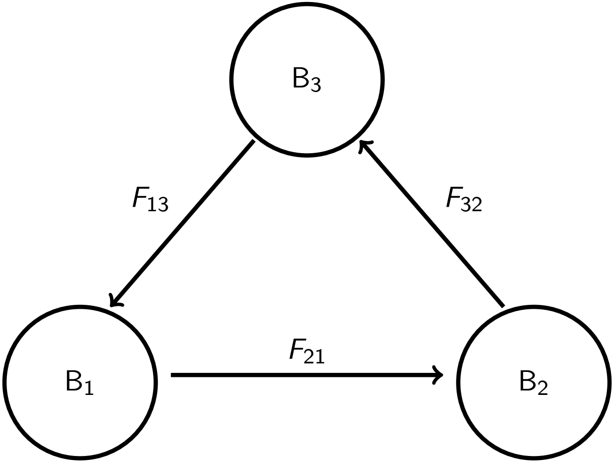
1. Selling other banks debt
2. Issue new debts, diluting original creditors

R3: Higher Debt Level Leads to Less Liquidation

R3a: One Bank Liquidated if Debts Low

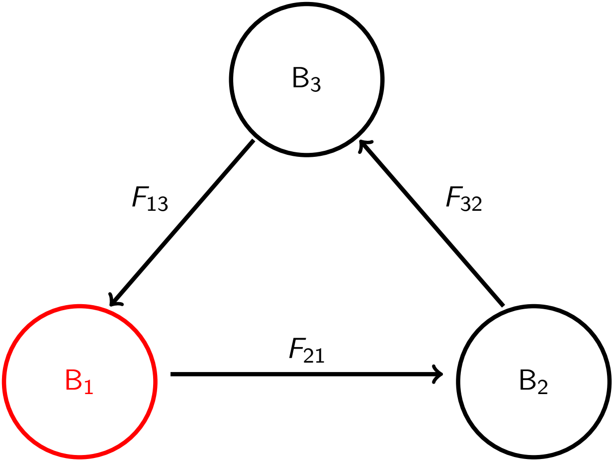
Result 3a: One Bank Liquidated if Debts Low

A ring network with 3 banks



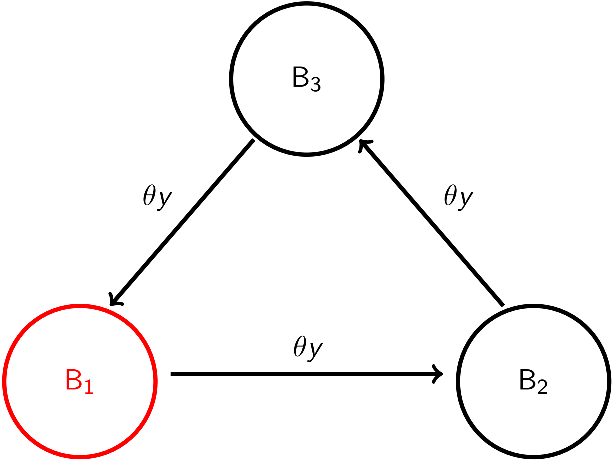
Result 3a: One Bank Liquidated if Debts Low

Bank 1 is shocked with $L = 2.5\theta y$



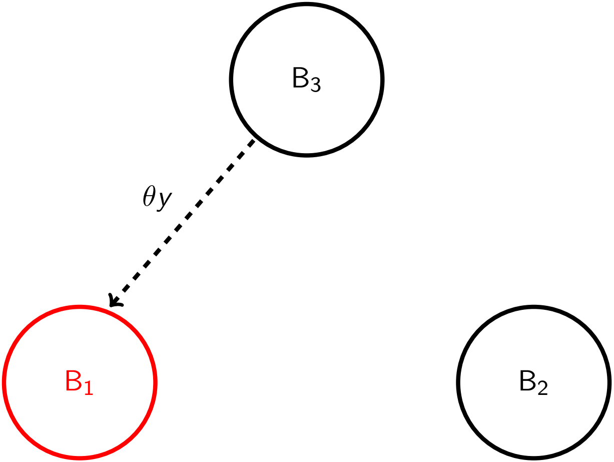
Result 3a: One Bank Liquidated if Debts Low

Suppose the face values are $F_{ij} = \theta y$



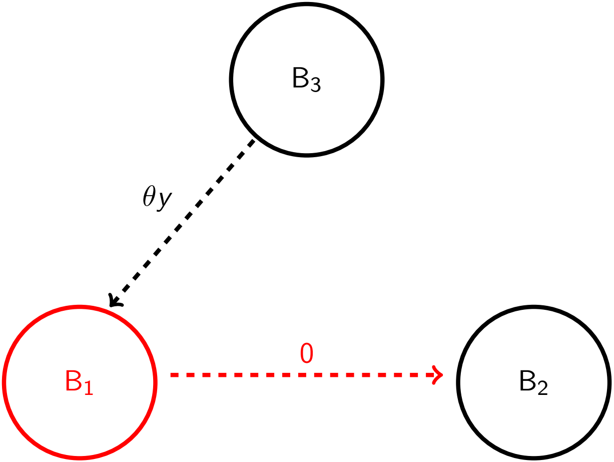
Result 3a: One Bank Liquidated if Debts Low

Bank 1 is liquidated because $\theta y + \theta y < L$



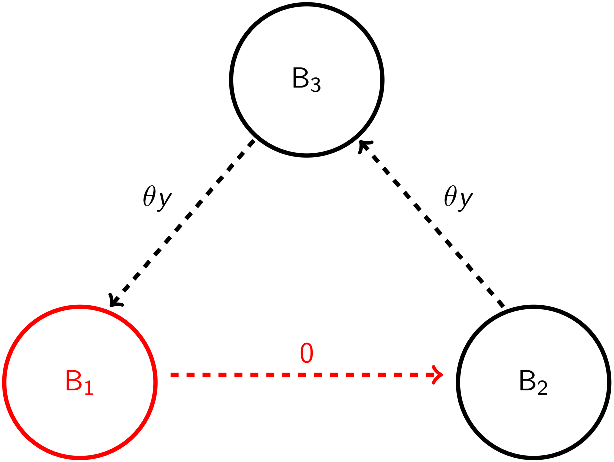
Result 3a: One Bank Liquidated if Debts Low

Bank 1 pays out 0



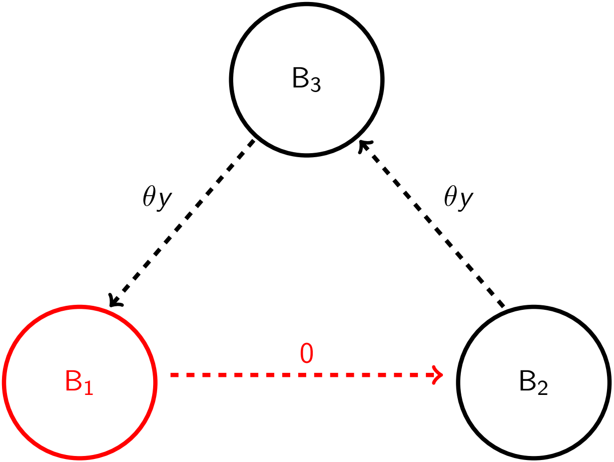
Result 3a: One Bank Liquidated if Debts Low

Bank 2 does not default as $0 + \theta y \geq \theta y$



Result 3a: One Bank Liquidated if Debts Low

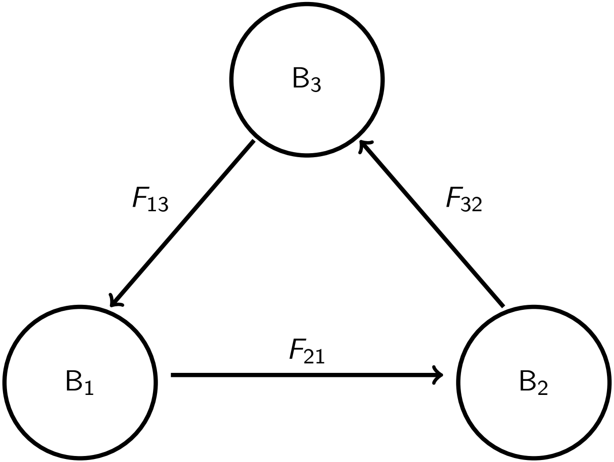
Verify Bank 3 does not default



R3b: No Banks Liquidated if Debts High

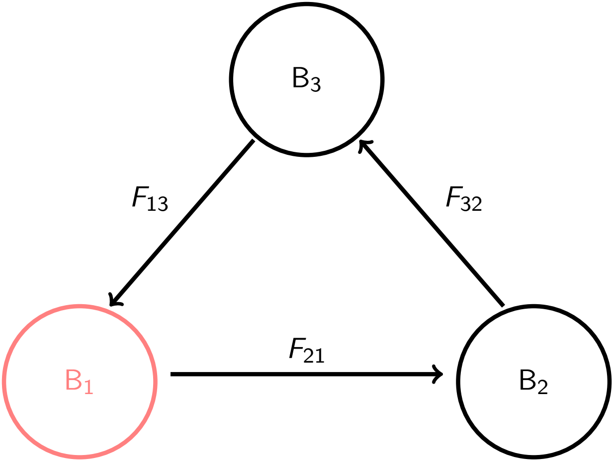
Result 3b: No Banks Liquidated if Debts High

A ring network



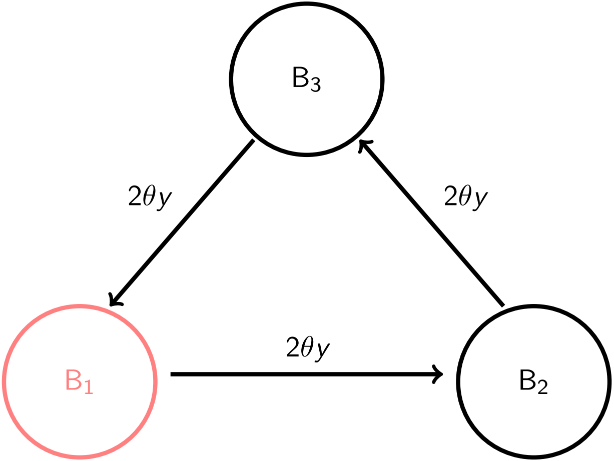
Result 3b: No Banks Liquidated if Debts High

Bank 1 is shocked with $L = 2.5\theta y$



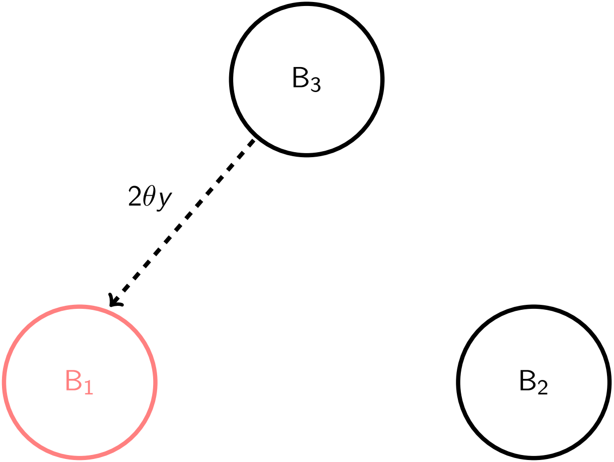
Result 3b: No Banks Liquidated if Debts High

Suppose now the face values are $F_{ij} = 2\theta y$



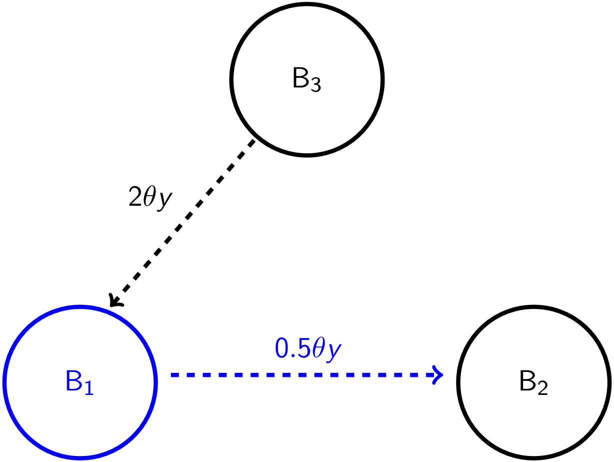
Result 3b: No Banks Liquidated if Debts High

Suppose bank 3 does not default



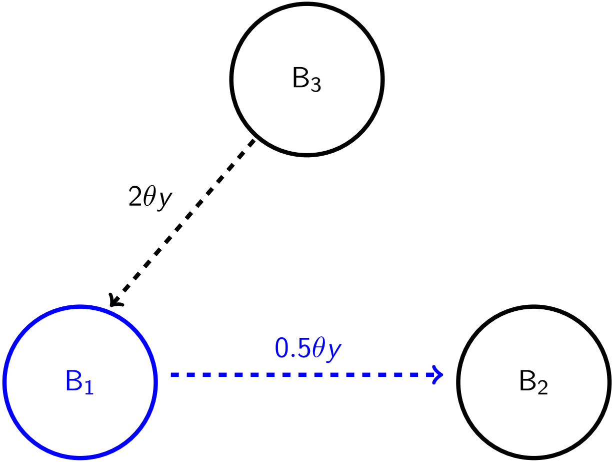
Result 3b: No Banks Liquidated if Debts High

Bank 1 is not liquidated $2\theta y + \theta y > L$, and pays out $0.5\theta y$



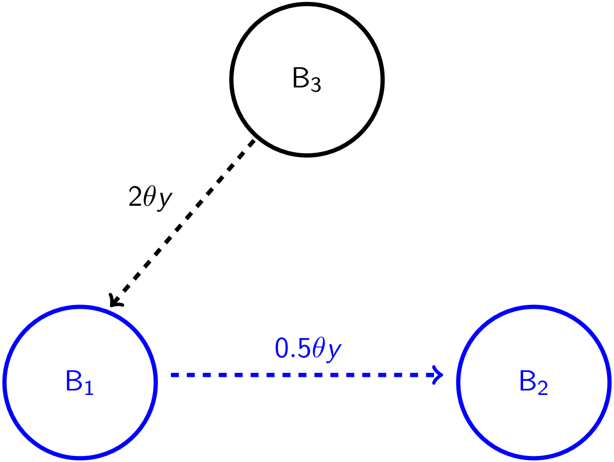
Result 3b: No Banks Liquidated if Debts High

Bank 2 is not shocked, hence not liquidated



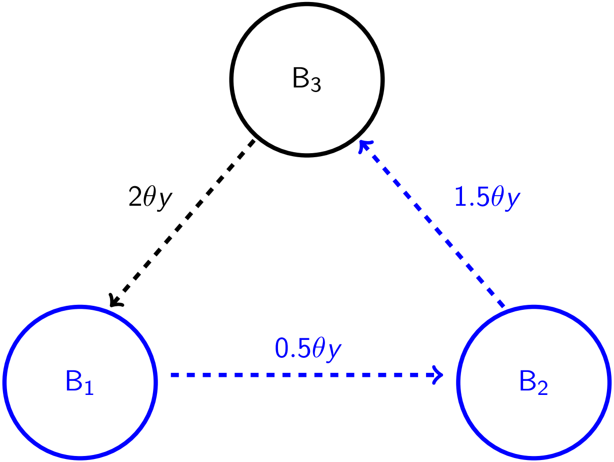
Result 3b: No Banks Liquidated if Debts High

Since $0.5\theta y + \theta y < 2\theta y$, Bank 2 defaults ...



Result 3b: No Banks Liquidated if Debts High

...and pays out $0.5\theta y + \theta y = 1.5\theta y$



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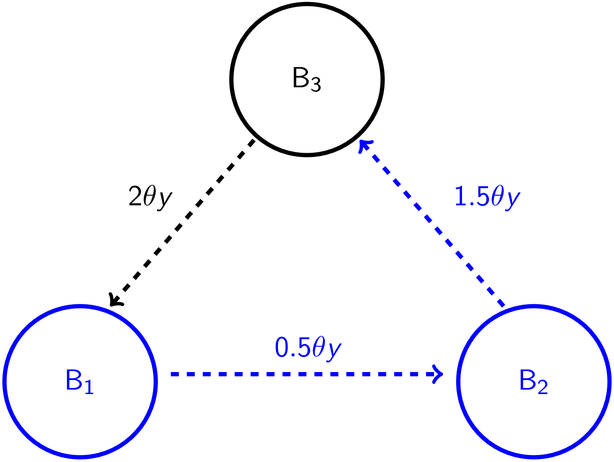


Intuition

With long-term debts, a bank is liquidated only if it is shocked

But a shocked bank can avoid liquidation if it raises enough liquidity

- from both issuing new senior debt
- and selling the long-term debts of other banks

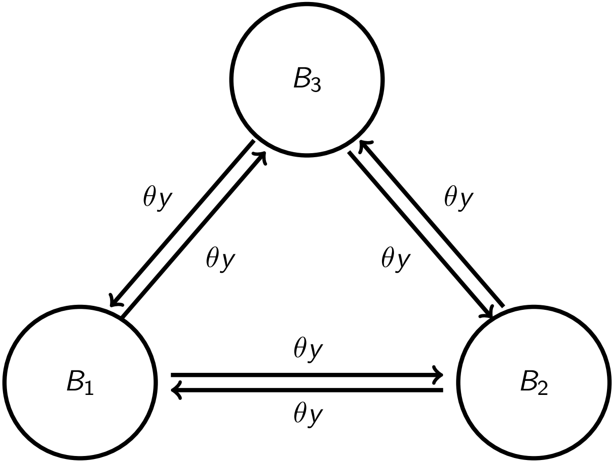
Higher debts level enhances the second channel

Result 4: Phase Transition

R4a: With Small Shocks, No Banks Liquidated in Complete Network when Debt Level High

R4a: No Banks Liquidated in CN when Debt Level High

Suppose $L = 2.5\theta y$



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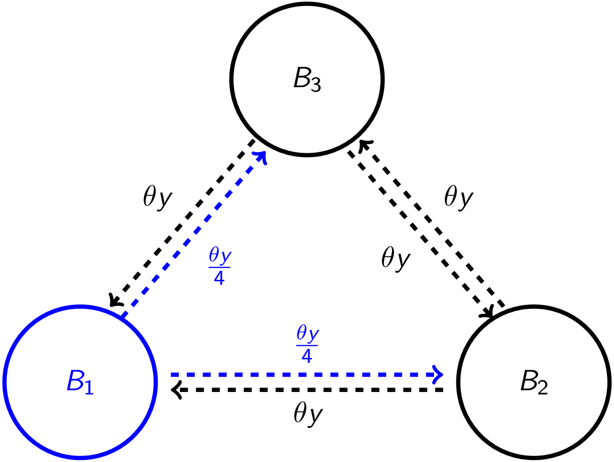
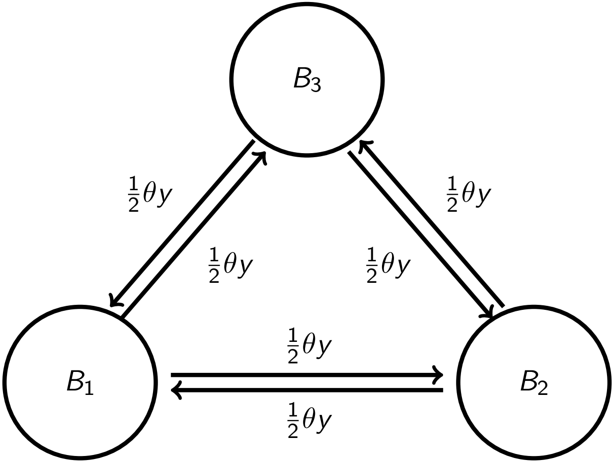


R4b: With Small Shocks, One Bank Liquidated in Complete Network when Debt Level Low

R4b: One Bank Liquidated in CN when Debt Level Low

Suppose $L = 2.5\theta y$



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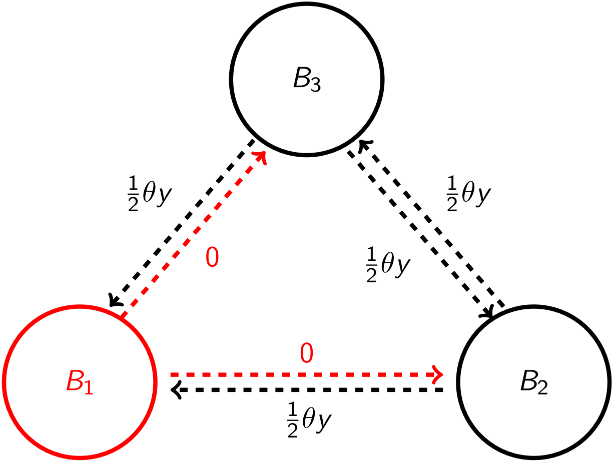
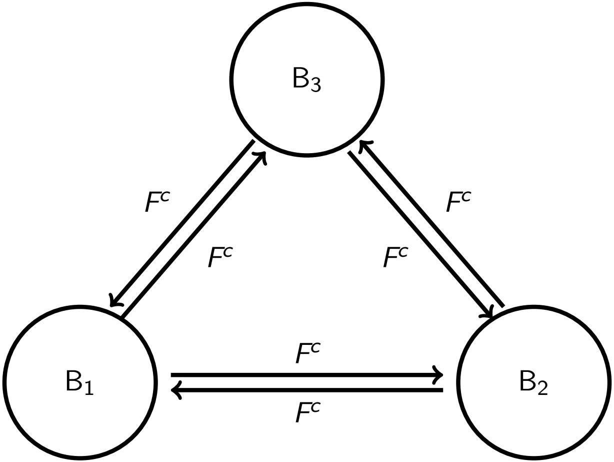


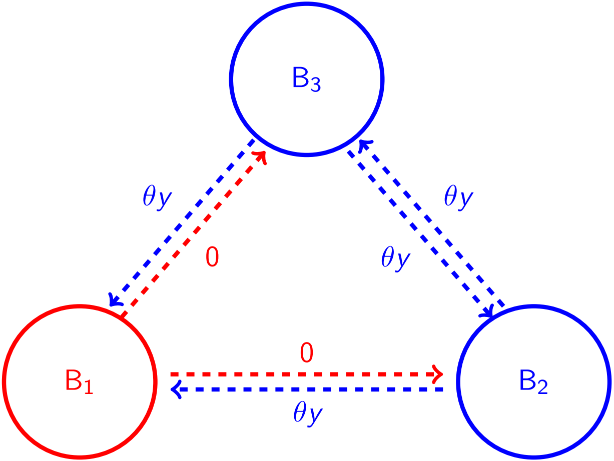
R4c: With Large Shocks, One Bank Liquidated in Complete Network

R4c: One Bank Liquidated in CN when Shocks Large

Suppose $L = 3.5\theta y$, $F^c \geq \theta y$



R4c: One Bank Liquidated in CN when Shocks Large



Why Higher Debts not Helpful?

Total liquidity in the system not enough

- Need to dilute more than θy, for each bank
- Net payment from each bank cannot be higher than θ for any F

Bank 1 liquidated for any F

Number of Liquidated Banks

With LT interbank debts, the number of liquidated banks $|\mathcal{D}|$ is

$$0 \leq |\mathcal{D}| \leq M$$

No banks are liquidated with enough good dilution

All shocked banks are liquidated with insufficient dilution

Implication:

Complete Network is the most stable network when shocks small attaining the lower bound

Complete Network is the least stable network when shocks large attaining the upper bound

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Are the two Phase Transitions Result the Same?

With short-term debt network

- Complete network most stable when shocks small
- Complete network least stable when shocks large, *only if F large*
  - transmitting more liquidity risk

With long-term debt network

- Complete network most stable when shocks small, *only if F large*
  - allows more dilution
- Complete network least stable when shocks large

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Conclusion

Short-term debt network

- Transmits liquidity risk
- Higher debt leads to more liquidation
- Netting helps reduce risk transmission

Long-term debt networks

- Facilitates dilution
- Higher debt leads to less liquidation
- Netting prevents good dilution

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