Bank Networks and Systemic Risk:
Micro-evidence from the National Banking Acts

Mark Paddrik — OFR
Haelim Park — OFR
Jessie Jiaxu Wang — ASU

Fed System Conference on Economic and Financial History
May 25th, 2016

Views expressed in this presentation are those of the speaker(s) and not necessarily of the Office of Financial Research.

How does financial architecture affect systemic risk?

- The financial system is highly interconnected.
  - "*risk of failure of large, interconnected firms must be reduced*" Volcker
  - Dodd-Frank Act mandates derivatives clearing via CCPs
- Ample theories on the role of network structures on stability
  - Allen and Gale (2000), Blume et al. (2011), Acemoglu et al. (2015)

How does financial architecture affect systemic risk?

- The financial system is highly interconnected.
  - "*risk of failure of large, interconnected firms must be reduced*" Volcker
  - Dodd-Frank Act mandates derivatives clearing via CCPs
- Ample theories on the role of network structures on stability
  - Allen and Gale (2000), Blume et al. (2011), Acemoglu et al. (2015)

... yet very limited structural analysis using real data

- financial linkages are not observable
- exogenous reshaping of network structures is rare

This paper examines bank networks in 1862, 1867.

"Those who cannot learn from history are doomed to repeat it." - Santayana

This paper examines bank networks in 1862, 1867.

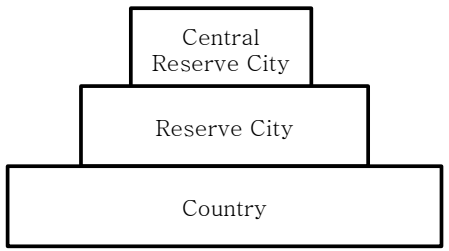
- A unique historical episode
  - bank networks were simply due to reserve deposits
  - National Banking Acts (1863-1864) reshaped network structure
  - five major banking crises in the National Banking era

☞ Our study shows that the National Banking Acts led to

- the concentration of bank linkages not only at the city level, but also at the institution level.

Bottom-to-Top Crisis

NBA Hierarchy



Top-to-Bottom Crisis

This paper quantifies how networks affect financial stability.

- How do such changes in network structure affect systemic risk?
  - build a model of bank reserve networks with liquidity withdrawals
  - simulate banking crises in empirical bank networks
- We find that a more centralized network is *robust-yet-fragile*
  - more robust to small shocks
  - more vulnerable to large shocks, especially to financial center banks
  - contagious withdrawals and liquidation have phase transition

Contributions

- Theoretical literature examining the relationship between financial networks and systemic risk.
  - Eisenberg, Noe 2001 MS; Elliott, Golub, Jackson 2014; Acemoglu, Ozdaglar, Tahbaz-Salehi 2015
- Empirical literature on stress-testing the resilience of networks.
  - Furfine 2003; Nier, Yang, Yorulmazer, and Alentorn 2007; Gai, Haldane, and Kapadia 2010; Glasserman and Young 2015; Gofman 2015; Stanton, Walden, and Wallace 2014
- Literature on the origin of banking crises during the National Banking era.
  - Sprague 1910; Kemmerer 1910; Calomiris and Gorton 1991; Bernstein, Hughson and Weidenmier 2010; Gorton and Tallman 2014

Outline

1. Background
2. Data and Empirical Findings
3. Model
4. Quantitative Analysis
5. Conclusion

Background

State Banking Era: 1837 - 1863

- There was no uniform currency, no central bank, no OCC.
- State-chartered banks issued their own *banknotes* with large dispersion in discounts.
- Banks had correspondent networks
  - shaped by interbank deposits/note-deeming + trade patterns
  - ☞ core-periphery structure with local hubs (Weber 2003)

National Banking Acts: 1863 - 1864

- Lincoln needed to finance the Civil War for the federal government.
- Secretary of Treasury Chase launched National Banking Act in 1863
  - national chartered banks with regulations: buy US bonds, reserves

National Banking Acts: 1863 - 1864

- Lincoln needed to finance the Civil War for the federal government.
- Secretary of Treasury Chase launched National Banking Act in 1863
  - national chartered banks with regulations: buy US bonds, reserves
  - uniform currency, the national banking system, OCC

National Banking Acts: 1863 - 1864

- Lincoln needed to finance the Civil War for the federal government.
- Secretary of Treasury Chase launched National Banking Act in 1863
  - national chartered banks with regulations: buy US bonds, reserves
  - uniform currency, the national banking system, OCC

- However, federal charters were not popular; NBA revision (1864) raised taxes on state banknotes 2%→10% ⇒ most converted

Transition in the Banking System

	United States			Pennsylvania		
Year	National	State	Savings	National	State	Savings
1860	0	1558	38	0	89	9
1861	0	1538	31	0	90	9
1862	0	1494	40	0	98	9
1863	139	1445	48	28	96	9
1864	643	1349	35	147	96	6
1865	1579	349	60	200	13	4
1866	1644	297	96	203	15	6
1867	1642	277	495	200	12	22
1868	1628	242	619	203	10	36
1869	1615	269	301	204	11	50

Interbank Network after the National Banking Acts

- The pyramid reserve requirements reshaped bank networks:
  - classified banks into 3 tiers
  - mandated reserve deposits with banks only at specific locations

Tier	Banks	Location	Reserve ratio	Deposit in up-tiers	Cash in vault
1	Central reserve city	NYC	25%	0	1
2	Reserve city	PHL, PIT	25%	1/2	1/2
3	Country banks	others	15%	3/5	2/5

☞ Reserve networks became 3-tiered and more centralized

Data and Empirical Results

Data Type & Sources

Construct bank networks for 1862 (pre) and 1867 (post) using:

1. *Bank Balance Sheets*

2. *Interbank Deposits*

Sources:

1. *Reports of the Several Banks and Savings Institutions of Pennsylvania*
   - State bank balance sheet with a list of correspondents (1862, 1867)

2. *National Bank Examiners' Reports - the National Archives*
   - National bank balance sheets with a list of reserve agents (1867)
   - regulatory data from annual bank examinations

Construct Bank Networks for 1862, 1867

State bank balance sheet with detailed reserve deposits at other banks (1862, 1867)

- *Reports of the Several Banks and Savings Institutions of Pennsylvania*

Due to the York County Bank, from the following named solvent banks respectively, on the 4th day of November, 1862, viz:

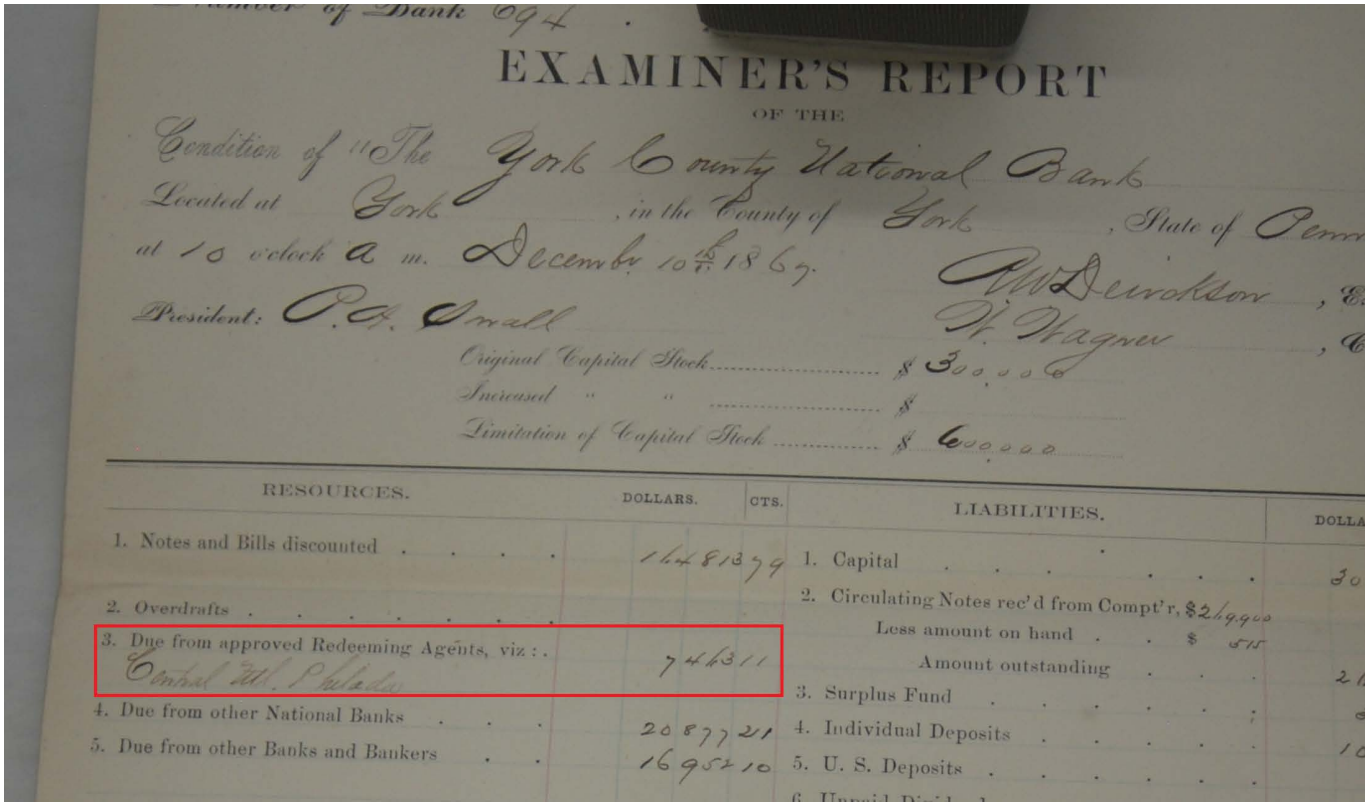
Bank of Commerce, New York	$4,654 73
Bank of Northern Liberties	61,276 78
Carlisle Deposit Bank	18 50
Jay Cook & Co	2,072 76
Exchange Bank, Pittsburg	561 99
Franklin Bank, Baltimore	33,797 87
Girard Bank, Philadelphia	5,600 26
Lancaster County Bank	233 17
Mechanics' Bank, Harrisburg	75 18
Western Bank, Baltimore	11,712 42
Western Bank, Philadelphia	2,142 72
York Bank	4,797 91
	126,944 29

Figure: Detailed due-from (deposits) of York County Bank in 1862

Construct Bank Networks for 1862, 1867

National bank balance sheet with reserve deposits at approved agents (1867)

- *National Bank Examiners' Reports*



EXAMINER'S REPORT

OF THE

Condition of "The York County National Bank

Located at York, in the County of York, State of Penn

at 10 o'clock a. m. December 10th 1867.

President: P. A. Small

Original Capital Stock ..... $ 300,000

Increased " " ..... $

Limitation of Capital Stock ..... $ 600,000

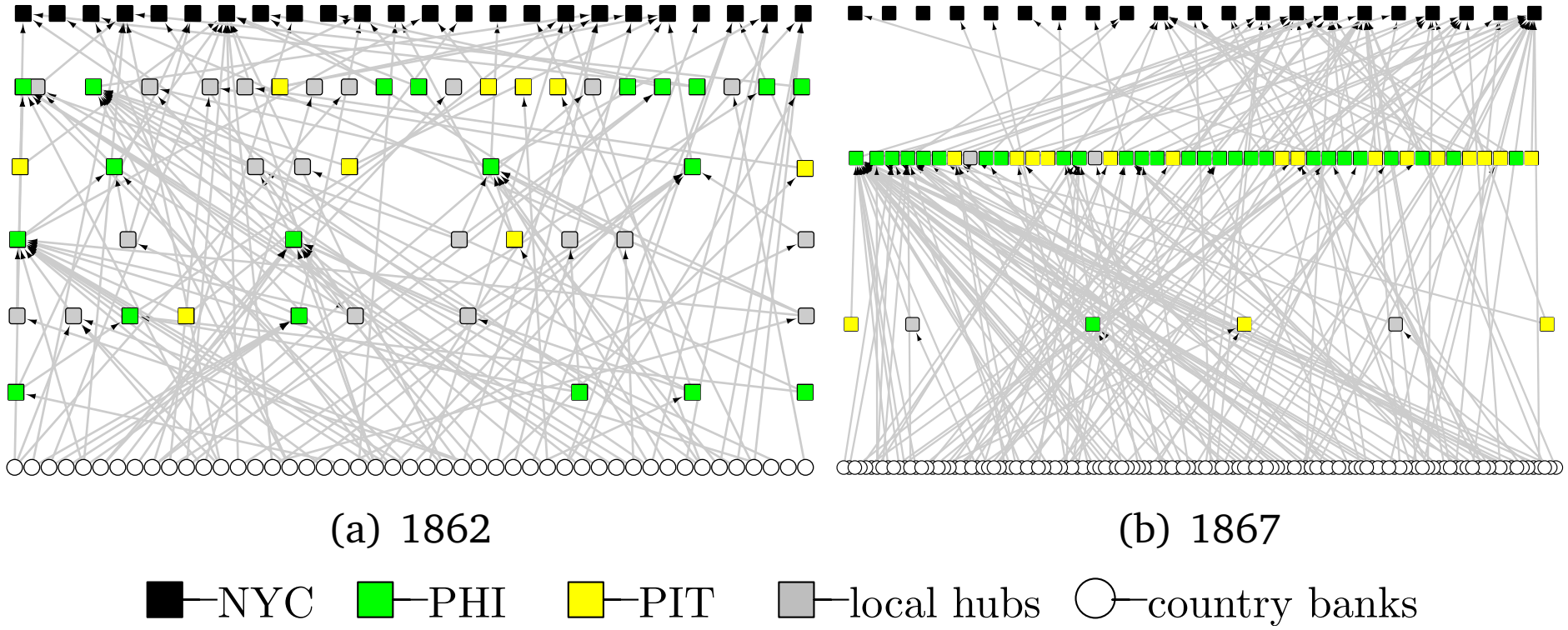
RESOURCES.	DOLLARS.	CTS.	LIABILITIES.	DOLLA
1. Notes and Bills discounted	144813	79	1. Capital	30
2. Overdrafts			2. Circulating Notes rec'd from Compt'r, $249900	
3. Due from approved Redeeming Agents, viz: Central Nat. Philada	74631	1	Less amount on hand $ 515	
			Amount outstanding	21
4. Due from other National Banks	20877	21	3. Surplus Fund	
5. Due from other Banks and Bankers	16952	10	4. Individual Deposits	
			5. U. S. Deposits	10

Figure: Reserve deposits of York County National Bank in 1867

Balance Sheet Statistics

	Philadelphia			*Pittsburgh*			*Country Banks*		
Year = 1862	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets									
Cash	20	0.213	0.101	7	0.181	0.064	63	0.115	0.068
Liquid Securities	20	0.304	0.144	7	0.317	0.125	63	0.182	0.135
Due from other banks	20	0.034	0.042	7	0.121	0.043	63	0.182	0.095
Loans	20	0.402	0.118	7	0.359	0.118	63	0.494	0.121
Against Total Liabilities									
Equity	20	0.240	0.055	7	0.363	0.071	63	0.282	0.091
Bank notes	20	0.133	0.096	7	0.391	0.173	63	0.404	0.213
Deposits	20	0.513	0.091	7	0.228	0.117	63	0.274	0.196
Due to other banks	20	0.091	0.086	7	0.006	0.006	63	0.014	0.016
Year = 1867	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets									
Cash	28	0.254	0.068	15	0.091	0.053	132	0.097	0.045
Liquid Securities	28	0.059	0.053	15	0.070	0.128	132	0.062	0.093
Due from other banks	28	0.055	0.041	15	0.066	0.045	132	0.099	0.063
Loans	28	0.395	0.087	15	0.488	0.088	132	0.404	0.139
Against Total Liabilities									
Equity	28	0.289	0.076	15	0.421	0.143	132	0.375	0.102
Bank notes	28	0.150	0.068	15	0.213	0.120	132	0.255	0.098
Deposits	28	0.490	0.117	15	0.347	0.205	132	0.337	0.162
Due to other banks	28	0.062	0.078	15	0.018	0.031	132	0.026	0.034

Reserve Networks: Concentration of bank linkages at the institutional level



It has been well documented that the NBA caused the immediate concentration of bank linkages at the city level.

The NBA caused the concentration of bank linkages at the institution level.

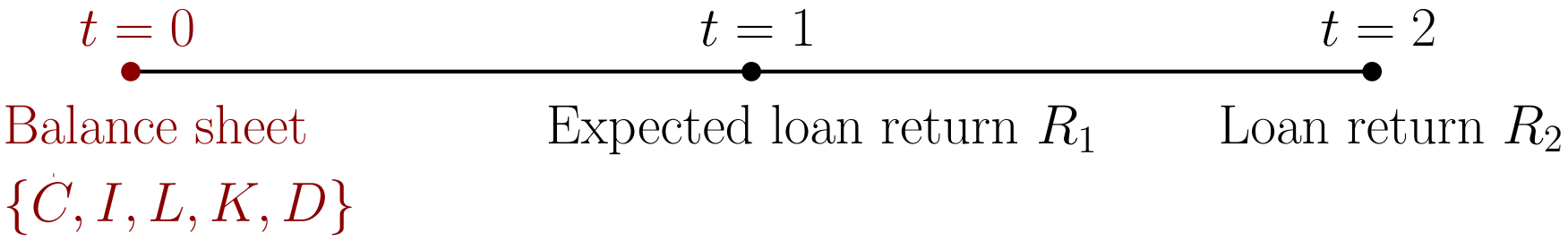
- in-degree for NYC banks doubled: 2.7 $\rightarrow$ 5.4

Model

Model: a network of interbank deposits

- Environment
  - N banks, household depositors, risk-neutral, no discounting
  - Banks have demand deposit, invest in long-term loan, and are subject to liquidity risk.
- Key features
  - Interbank liability linkages
  - Endogenous liquidity withdrawal
  - Two periods of clearing equilibrium
- Builds on Eisenberg and Noe (2001 MS); Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015 AER).

Model: timeline



Model: timeline

$t = 0$	$t = 1$	$t = 2$
Balance sheet $\{C, I, L, K, D\}$	Expected loan return R_1	Loan return R_2

- Bank i's balance sheet is

Asset	Liability
Cash C_i	Capital K_i
Loan I_i	Deposit D_i
Due-from $\sum_k L_{ik}$	Due-to $\sum_j L_{ji}$

- Interbank deposit network is L.
- $L_{ij} > 0$ denotes bank i deposits at j.

Model: timeline

$t = 0$	$t = 1$	$t = 2$
Balance sheet	Expected loan return R_1	Loan return R_2
$\{C, I, L, K, D\}$	Withdrawal W^L, W^D	
	Payment I^l, I^{d1}, X^L, X^D	

Model: timeline

$t = 0$	$t = 1$	$t = 2$
Balance sheet	Expected loan return R_1	Loan return R_2
$\{C, I, L, K, D\}$	Withdrawal W^L, W^D	
	Payment I^l, I^{d1}, X^L, X^D	

- Loan return

$$\log R_{t+1} = \log R_t + \varepsilon_{t+1}, \quad \varepsilon_t \sim N(\nu_t, \sigma_t, \varrho_t).$$

- Clearing payment among banks X^L, to households X^D
- Early withdrawals by bank depositors W^L, by households W^D
- Early liquidation $\mathbb{I}^l$: reserve + cash $<$ withdrawals
- Early default $\mathbb{I}^{d1}$: reserve + cash + loan liquidation $<$ withdrawals

Model: timeline

$t = 0$	$t = 1$	$t = 2$
Balance sheet	Expected loan return R_1	Loan return R_2
$\{C, I, L, K, D\}$	Withdrawal W^L, W^D	Payment I^{d2}, Y^L, Y^D
	Payment I^l, I^{d1}, X^L, X^D	

Model: timeline

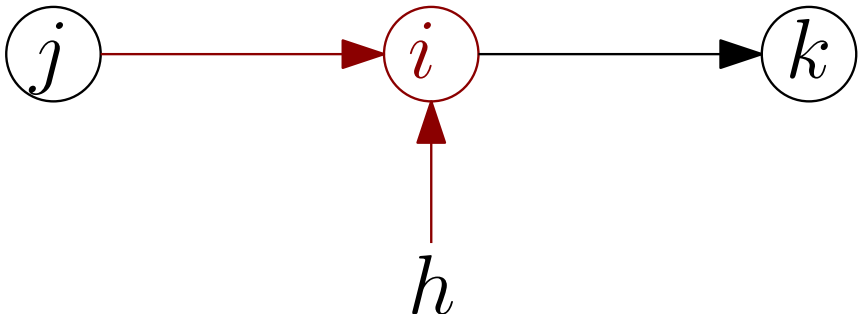
$t = 0$	$t = 1$	$t = 2$
Balance sheet	Expected loan return R_1	Loan return R_2
$\{C, I, L, K, D\}$	Withdrawal W^L, W^D	Payment I^{d2}, Y^L, Y^D
	Payment I^l, I^{d1}, X^L, X^D	

- If not liquidated, loan returns IR_2.
- Clearing payment among banks Y^L, to households Y^D
- Default $\mathbb{I}^{d2}$: reserve + cash + loan return $<$ deposits

Early Withdrawal Scenarios: fundamentals

(A). Depositors withdraw when holder bank has low expected return.

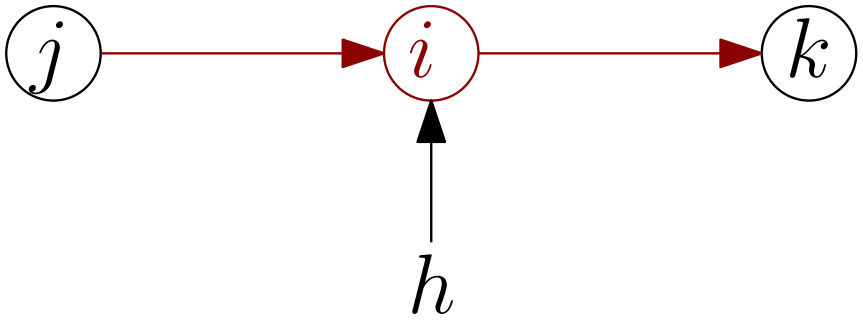
$\Pr(i \text{ defaults at } t_2 \mid R_{i,1}) > \bar{p} \Rightarrow$ all of i's depositors withdraw.



Early Withdrawal Scenarios: vertical contagion

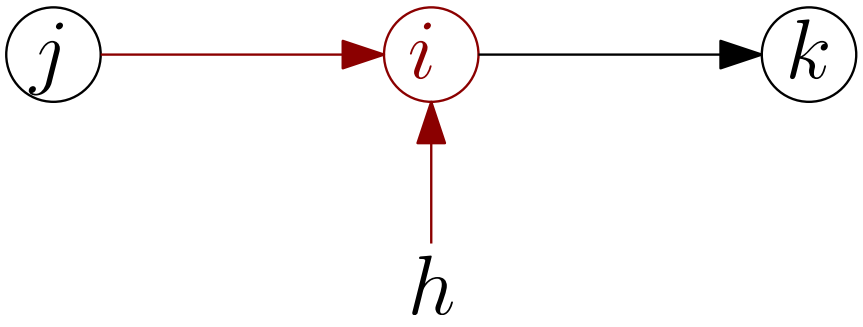
(B). i withdrawals from k if i has illiquidity due to withdrawals.

(C). If k defaults on i, all of i's depositors withdraw.



Early Withdrawal Scenarios: horizontal contagion

(D). j withdrawals from i if other depositors of bank i withdraw.



Early Withdrawal Clearing Equilibrium

- Given balance sheet $\{C, I, K, D, L\}$, expected loan returns R_1, withdrawal W^L and W^D, early liquidation and default $\mathbb{I}^l$ and $\mathbb{I}^{d1}$, total cash flow of i (who has withdrawals) at $t = 1$ is

$$H_i^1 = C_i + \sum_k W_{ik}^L X_{ik}^L + \mathbb{I}_i^l I_i (1 - \xi_l).$$

Early Withdrawal Clearing Equilibrium

- Given balance sheet $\{C, I, K, D, L\}$, expected loan returns R_1, withdrawal W^L and W^D, early liquidation and default $\mathbb{I}^l$ and $\mathbb{I}^{d1}$, total cash flow of i (who has withdrawals) at $t = 1$ is

$$H_i^1 = C_i + \sum_k W_{ik}^L X_{ik}^L + \mathbb{I}_i^l I_i (1 - \xi_l).$$

- If $H_i^1 < i$'s withdrawal demand, i defaults and pays X_i^L and X_i^D to depositors *pro rata*.

Early Withdrawal Clearing Equilibrium

- Given balance sheet $\{C, I, K, D, L\}$, expected loan returns R_1, withdrawal W^L and W^D, early liquidation and default $\mathbb{I}^l$ and $\mathbb{I}^{d1}$, total cash flow of i (who has withdrawals) at $t = 1$ is

$$H_i^1 = C_i + \sum_k W_{ik}^L X_{ik}^L + \mathbb{I}_i^l I_i (1 - \xi_l).$$

- If $H_i^1 < i$'s withdrawal demand, i defaults and pays X_i^L and X_i^D to depositors *pro rata*.

- Interbank reserve deposit payment X^L + household deposit payment X^D form an **early withdrawal clearing equilibrium** of the bank network at $t = 1$.

- The clearing equilibrium exists and is unique. (Eisenberg Noe 2001)

Final Date Clearing Equilibrium

- For all banks with no early withdrawals, loan returns R_2 realize, total cash flow of i at $t = 2$ is

$$H_i^2 = C_i + I_i R_{i,2} + \sum_k \left(W_{ik}^L X_{ik}^L + (1 - W_{ik}^L) Y_{ik}^L \right)$$

- If $H_i^2 < i$'s deposits, i defaults and pays Y_i^L and Y_i^D to depositors *pro rata*.

- Interbank reserve deposit payment Y^L + household deposit payment Y^D form a **final date clearing equilibrium** of the bank network at $t = 2$.

- The clearing equilibrium exists and is unique.

Quantitative Analysis

Quantitative Analysis

- Construct banking systems using real data
  - $\{C, I, K, D, L\}$ from bank balance sheets in 1862 and 1867
- Top-to-bottom crises: correlated return shocks R_1 to NYC banks
- Bottom-to-top crises: correlated liquidity shocks W^D to country banks
- Measures for systemic risk
  - joint probability of liquidation/default
  - expected costs from liquidation/default
  - liquidation/default due to contagion

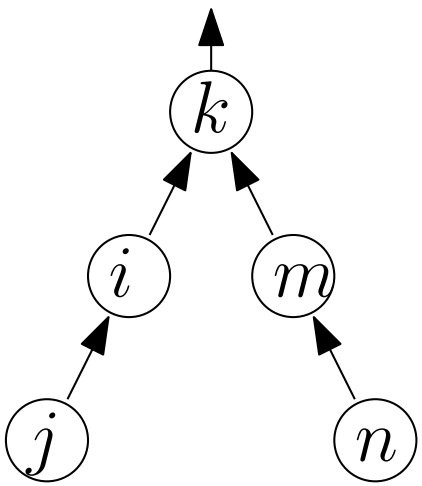
Quantitative Analysis: Top-to-Bottom Crises

"It was the suspension of cash payments and not bank runs nor bank failures through which the public in the rest of the country experienced the effects of banking panics." (Wicker, 2000)

- 4 out of 5 major banking panics began due to investment loss in NYC and spread to the rest of the country.

  - 1873: failure of Jay Cooke
  - 1884: failure of Grant and Ward
  - 1890: failure of Decker Howell and Co.
  - 1907: failure of knickerbocker trust

Quantitative Analysis: Top-to-Bottom Crises



Negative shock to $R_{k,1}$

$\Rightarrow$ Withdrawals from i, m and k's household depositors

$\Rightarrow$ k liquidates and defaults.

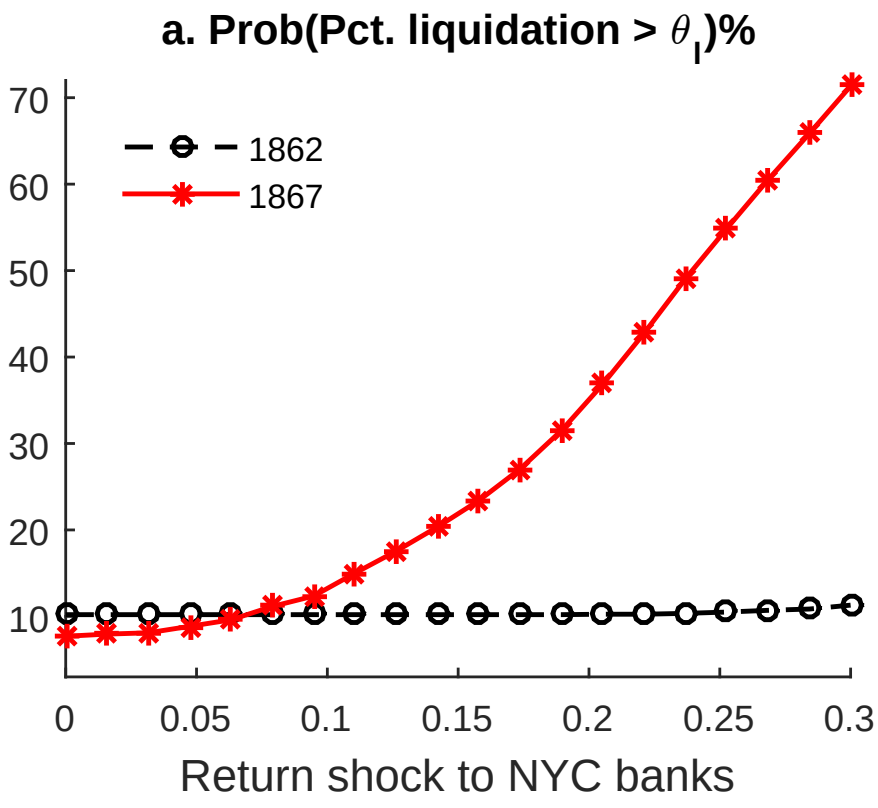
$\Rightarrow$ j and n withdraw from i and m.

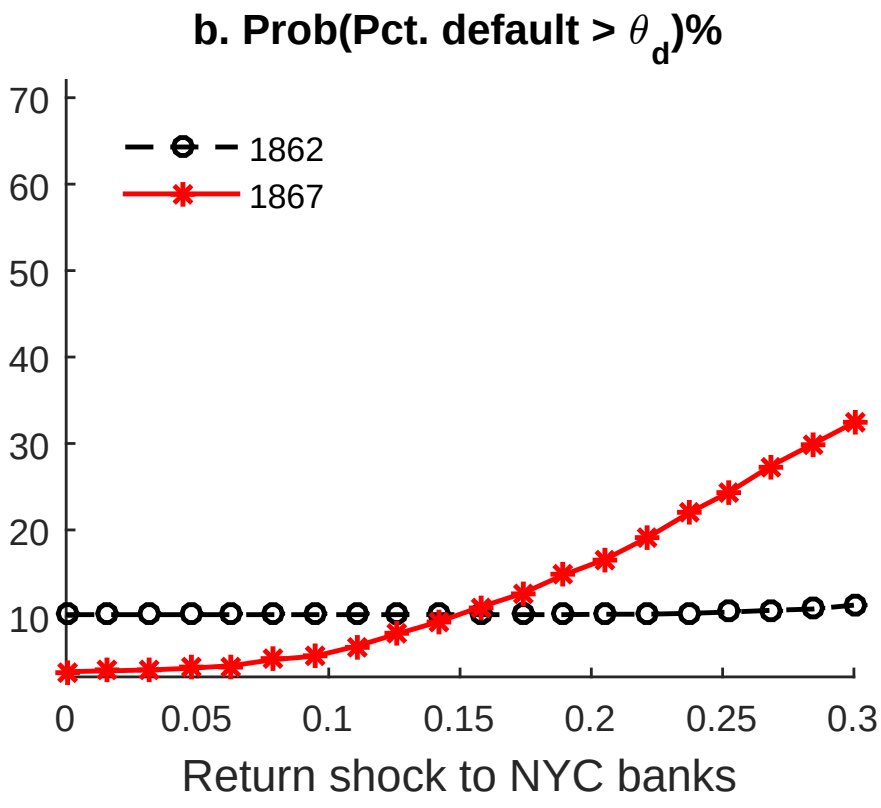
$\Rightarrow$ i and m liquidate and default, etc.

Top-to-Bottom Crises: phase-transition

1867 network is robust to small shocks but not to large shocks

☞ "robust-yet-fragile", knife-edge dynamics as in Haldane (2013)

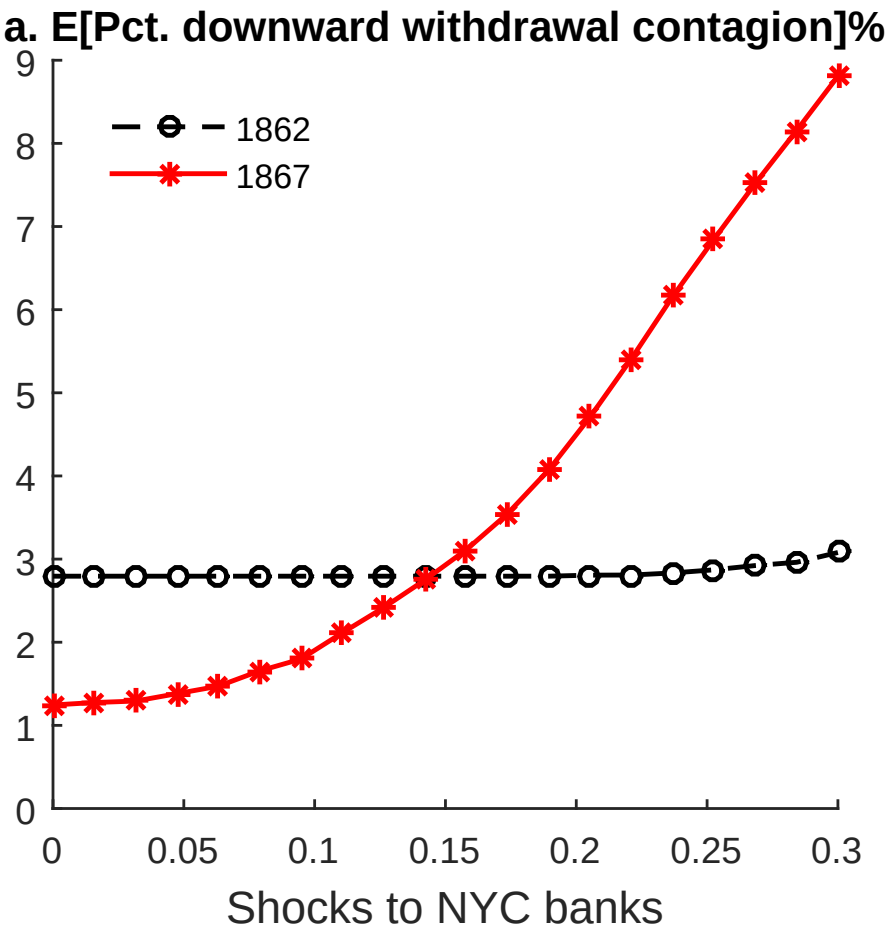


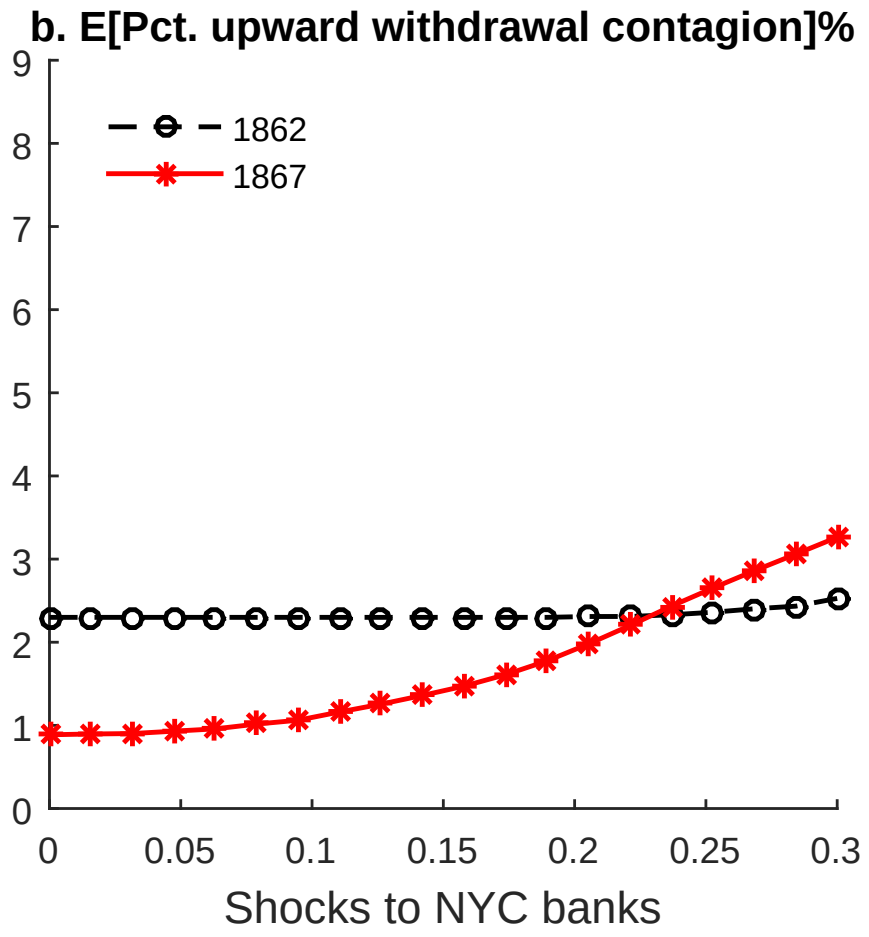


Mechanism: downward withdrawal contagion

Small shocks: diversification limits downward contagion

Large shocks: centralized linkages act as a mechanism for contagion





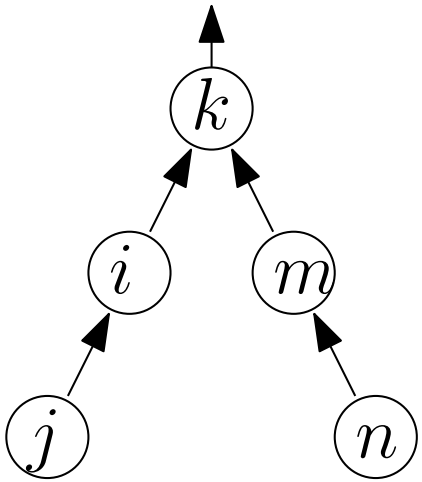
Quantitative Analysis: Bottom-to-Top crises

"A withdrawal of reserves by the bottom of the pyramid during a panic could thus result in a rapid depletion of reserves within the banking system." (Bankers' Magazine 1907 July)

- Due to agricultural cycles, country banks experienced farmers' withdrawal in the spring and fall and thus liquidity shortages.

- 1893: bank suspensions occurred outside NYC, mainly in the South and the West.

Quantitative Analysis: Bottom-to-Top crises



Shocks to W_j^D and W_n^D

$\Rightarrow$ j and n withdraw from i and m.

$\Rightarrow$ i and m withdraw from k.

$\Rightarrow$ Household depositors of i, m, and k withdraw.

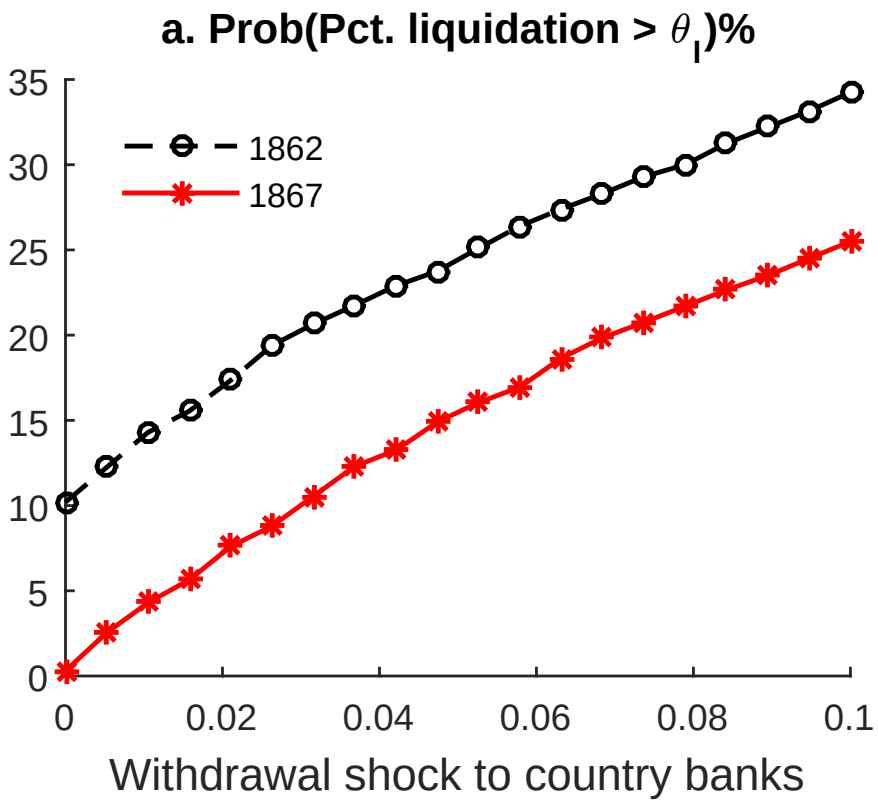
$\Rightarrow$ k liquidates and defaults.

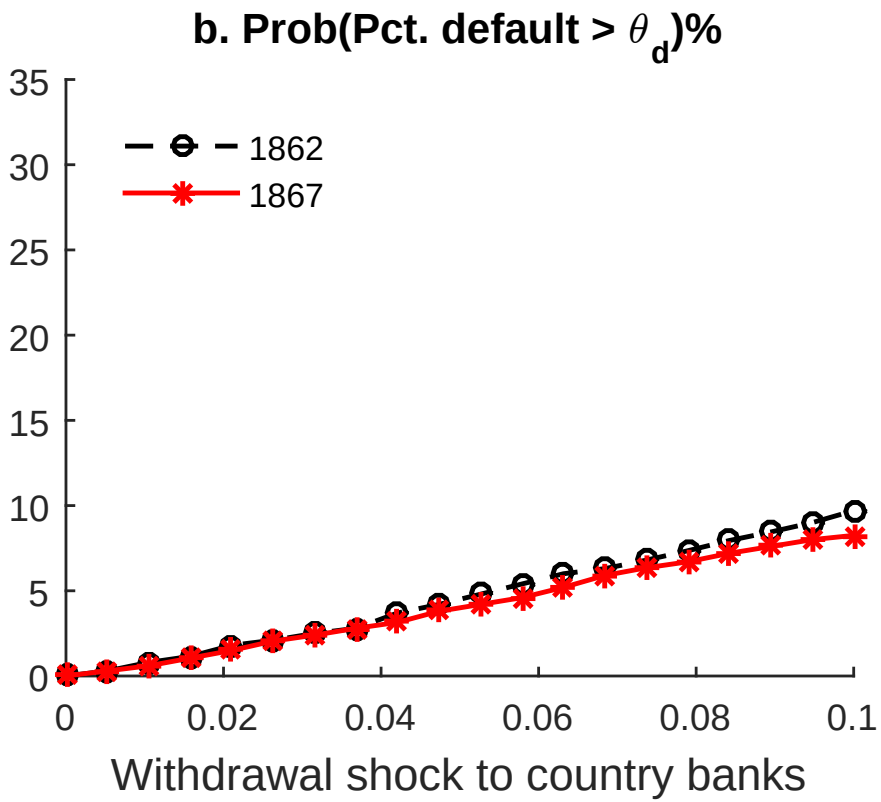
$\Rightarrow$ i and m liquidate and default, etc.

Bottom-to-Top Crises

1867 network is generally more robust to illiquidity of country banks

☞ NYC banks held more cash





Conclusion

An important topic: bank networks and systemic risk

A unique historical and quantitative approach

- examine bank networks in 1862 and 1867
- quantify effect of networks on systemic risk

Key findings

- The Acts reshaped the bank reserve networks to be more centralized.
- Such more centralized network is robust-yet-fragile to liquidity crises.

Benchmark Parameter Calibration

Parameter	Notation	Value
Equity loss threshold to trigger liquidation	κ	0.3
Liquidation cost proportional to loan size	ξ_l	0.2
Default cost proportional to shortfall	ξ_d	1.5
Average loan return rate	$\bar{e}$	0
Volatility of loan return rate	σ_e	0.1
Systemic threshold for fraction of bank liquidation	θ_l	20%
Systemic threshold for fraction of bank defaulting	θ_d	20%
Liquidation event	$-\Delta$assets $> \kappa\times$equity	
Default event	$h_i < \sum_j L_{ji} + d_i$	
Systemic liquidation event	$> \theta_l$ of banks liquidate	
Systemic default event	$> \theta_d$ of banks default	