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

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Abstract

The National Banking Acts of 1863-1864 (the Acts) established rules for interbank reserve deposits, which created a more centralized bank network. Using unique data on bank balance sheets and detailed reserve deposits due from other banks in 1862 and 1867 Pennsylvania, we quantify how changes in bank networks affected systemic risk in a model of interbank networks with liquidity withdrawal. Our results show that a centralized network is "robust-yet-fragile" to liquidity crises: While the post-Acts network became more robust against liquidity shocks to financial center banks in normal times, it was more vulnerable in times of aggregate distress.

JEL Classification: G21, G28, D85, L14

Keywords: Bank networks, financial interconnectedness, systemic risk, contagion, the National Banking Acts

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1 Introduction

The recent financial crisis has sparked growing scrutiny of the role that interconnected financial architecture plays in global financial stability. Paul Volcker, former Chairman of the Federal Reserve, commented in 2011 that "[T]he risk of failure of large, interconnected firms must be reduced, whether by reducing their size, curtailing their interconnections, or limiting their activities." Based on theoretical frameworks, many economists have identified financial interconnectedness as a critical source of systemic risk (e.g. Allen and Gale (2000), Elliott, Golub, and Jackson (2014), Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015)).

Despite the importance and desire to develop structural solutions to contagion concerns, the ability to analyze the effects of such policy decisions is limited. In particular, empirical analysis on interconnectedness is challenging due to the lack of detailed data on the precise linkages among financial institutions. Often, the topology of financial networks is unknown; Even if it is known for a particular contract type, the topology of the full financial network of risk exposure is unavailable because linkages can be formed by a diverse range of contracts with limited data coverage. As a result, existing studies rely mainly on numerical simulations to understand the role of the networks as shock propagation and amplification mechanisms.

We overcome these limitations by examining a historical episode when financial linkages involve single type of contracts and the linkage data is readily available. We look at bank reserve deposit networks before and after the passage of the National Banking Acts of 1863-1864 (the Acts) which shaped dramatically the architecture of bank networks.[1] Established primarily to finance the Civil War, the Acts set reserve requirements that classified national banks into three distinct tiers and mandated that they hold reserves with banks based on specific locations. These requirements not only led to a highly hierarchical banking network, placing New York City banks at the top of its pinnacle, but also generated a high degree of linkage concentration.

We start by constructing a hand collected micro-level dataset for all banks in Pennsylvania (and New York City) from state banking reports and national bank examiners' reports. The dataset includes bank balance sheets with detailed information on "due from other banks" by

[1] The National Banking Acts of 1863-1864 created a dual banking system, which allowed commercial banks to choose to organize as national banks with a charter issued by the Office of the Comptroller of the Currency (OCC) or as state banks with a charter issued by a state government. Because each state implemented a different set of banking laws, the choice of charter determined banks regulatory requirements.

individual debtor bank on the asset side of the balance sheets. The dataset not only identifies the topology of bank reserve deposit networks, but also the intensity of these linkages.

Data show that the post-Acts bank reserve deposit network in 1867 displayed a three-tied and much more centralized structure compared to that of 1862. Before the Acts, reserve network in 1862 demonstrated a core-periphery structure with multiple tiers of banks in the middle of the reserve deposit chain. After the Act, the reserve deposit network remained its core-periphery structure. However, it created a 3-tiered hierarchical structure and became much more centralized compared to 1862. Country banks sent their major deposits now to a single reserve city bank, in Philadelphia or Pittsburgh, and the reserve city banks deposited with one to two New York City banks. Such concentration of bank reserve deposit linkages placed New York City banks in a crucial position of liquidity shocks propagation and potentially could have contributed to banking crises during the National Banking era.

To quantitatively evaluate the role of centralized networks to financial stability, we then examine how liquidity shocks propagate through bank networks before and after the National Banking Acts using the newly constructed dataset. We begin by building a model of interbank reserve networks with liquidation based on Eisenberg and Noe (2001). The micro-level data of banking deposit reserves with each other provides the interbank liability structure to feed into the model. This structure thus allows us to define a unique payment system in equilibrium, which we use as a basis for simulating shocks of various types, sizes, and origins. The goal is to quantify how changes in the structure of bank networks affected the stability of the banking system.

In particular, the model is used to simulate the effects of two types of systemic liquidity crises on the banking system. First, we examine the resilience of the banking system when New York City banks suffered from unexpected financial shocks. Second, we examine the resilience of the banking system as banks outside the city withdrew deposits due to seasonal fluctuations in demand for money and credit. We compare the resilience of the banking system to these shocks before and after the passage of the National Banking Acts.

We find that the National Banking Acts induced a "*robust-yet-fragile*" nature of bank networks. The banking system became more robust to liquidity shocks originating from New York City banks during normal times. However, it became more vulnerable to these shocks in bad times when the banking sector on average is experiencing low returns or high volatility. At the same time, the banking sector became more vulnerable to liquidity shocks driven by the deposit withdrawals of banks outside the financial centers during normal and bad times.

Our results show that financial stability depends crucially on the topology of networks, the origin of financial shocks, and the state of the economy. When the aggregate economy features low uncertainty (volatility of loan returns), a more centralized bank network is more "robust." This outcome is thus due to two effects. First, it shortens the network of bilateral exposures and therefore lowers the chances of contagion from indirect counterparties. Second, the concentration increases the number of reserve depositors each reserve agent has. This facilitates risk diversification so that each reserve agent is more resilient to the liquidity withdrawal of any single bank depositor. However, when aggregate uncertainty is high, or when loans experience low returns on average, systemic liquidity events are more likely to occur. The concentration creates greater contagion risk as shocks can propagate from banks in financial centers to a large number of debtor banks in the system. This "*robust-yet-fragile*" nature of the post-Acts bank networks is consistent with the "knife-edge flipping" concept in Haldane (2013) and theoretical findings in Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) and Gai and Kapadia (2010).

Our paper makes two major contributions to the literature. Firstly, we apply historical bank networks data and show quantitatively how liquidity shocks may be transmitted in the system under distinct network structures. As such, this paper fits into a key area of theoretical research arguing that certain network structures lead to contagion and systemic risk.[2] For example, Allen and Gale (2000) show that financial system is more stable when network connection is denser. Elliott, Golub, and Jackson (2014) show that the degree of integration and diversification has non-monotonic effect on default cascades. Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) demonstrate that financial network has a robust-yet-fragile nature: financial contagion shows a phase transition with respect to network connectivity and the size of shocks. Another line of literature embeds endogenous linkage formation and examines how systemic risk is exacerbated under various frictions, such as moral hazard in Castiglionesi and Navarro (2011), incomplete

[2] An incomplete list includes Allen and Gale (2000), Eisenberg and Noe (2001), Dasgupta (2004), Nier, Yang, Yorulmazer, and Alentorn (2007), Gai and Kapadia (2010), Haldane and May (2011), Gai, Haldane, and Kapadia (2011), Caballero and Simsek (2013), Zawadowski (2013), Elliott, Golub, and Jackson (2014), Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), Glasserman and Young (2015a), Greenwood, Landier, and Thesmar (2015), Wang (2015).

markets in Farboodi (2014), Knightian uncertainty in Caballero and Simsek (2013) and incomplete contingent contracts in Wang (2015). However, due to the difficulties in identifying exact linkages among financial institutions, not much work has been able to demonstrate contagion using empirical networks. Our paper fills this gap by using empirically observed reserve deposit relationships to construct bank networks.

Secondly, we show empirically how the pyramiding of bank reserves contributed to liquidity crises during the National Banking era. While several studies have discussed how the structure of reserve requirements contributed to systemic risk, they did not provide direct evidence on how it turned liquidity crises systemic.[3] Moreover, none of these studies discuss how changes in the concentration of bank reserves and bank linkages affected systemic risk before and after the passage of the National Banking Acts. In contrast, we provide direct evidence using micro-level data.

2 Historical Background

This section delves into three key aspects of the U.S. banking system during the National Banking Era: (1) the National Banking Act, which created a system of federally chartered banks and regulations, (2) the correspondent banking system, which was characterized by the concentration of bank reserves in reserve and central reserve cities and contributed to the fragility of the banking sector, and (3) the Banking Panics of the National Banking Era.

2.1 National Banking Acts

Until 1864, commercial banks were chartered and regulated by states. With the passage of the National Banking Act of 1864, a federal role in the banking system was introduced. The intent of the legislation was to establish a system of national banks and assert federal control over the monetary system in an endeavor (1) to create an active secondary market for Treasury securities to help finance the Civil War, (2) to create a uniform national currency, and (3) to create a system of national banks. To supervise nationally chartered banks, the act created the Office of the Comptroller of the Currency (OCC).

[3] For example, Calomiris and Gorton (1991); Sprague (1910); Kemmerer (1910); Bernstein, Hughson, and Weidenmier (2010); Miron, Mankiw, and Weil (1987); Miron (1986); Gorton and Tallman (2014); Wicker (2000).

The first goal of the Acts was to help finance the Civil War. The National Banking Act required national banks to deposit a minimum quantity of eligible U.S. Treasury bonds before issuing bank notes. In exchange, the issuing bank received banknotes worth either 90% or the market value of the deposited bonds, whichever was lower. If the bank wished to issue additional notes to generate more profits, then the bank had to increase its holdings of Treasury bonds. This system was designed to create a more active secondary market for Treasury bonds and thus lowered the cost of borrowing for the federal government.

The second goal of the Acts was to create a uniform national currency. Prior to the passage of the National Banking Act, hundreds of different currencies circulated at different discount rates in the United States. In order to resolve the discounting problem, the Act required all national banks to accept at par the banknotes of other national banks. In addition, all national banknotes were printed by the Comptroller of the Currency on behalf of the national banks to guarantee standardization in appearance and quality.

The third provision of the Acts was to create a system of nationally chartered banks. National banks were subject to federal regulations, which were stricter than their state bank counterparts. National banks had capital requirements and reserve requirements. In addition, they were prohibited from making real estate loans and could not lend to any single person an amount exceeding 10% of the bank's capital.[4] The OCC became responsible for conducting an annual inspection of national banks.

The National Banking Act of 1863 failed to establish a significant base of federally chartered banks, as it did little to push state banks to convert to national banks or discourage the circulation of state bank notes. As of October of 1863, there were only 63 national banks chartered OCC (1863) and the volume of state bank notes in circulation remained unchanged. In June of 1864, a revision of the act was passed to encourage more state banks to apply for a national bank charter. The revision imposed a tax on all bank notes issued by state banks of 2%, which was raised to 10% in March of 1865. After the revision, many state banks joined a national charter, as shown in Table 1. The number of state banks decreased from 1,445 in 1863 to 242 in 1868, while the number of national banks increased from 139 to 1,628. However, in the 1880s,

[4] However, Calomiris and Carlson (2014) explored examiners reports from the 1890s and found that these laws were not strictly enforced.

Table 1. US & Pennsylvania Bank Charter Growth and Transition

Year	United States			Pennsylvania		
	National	State	Savings Banks	National	State	Savings Banks
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

Source: Merchants & Bankers Almanac 1860 thru 1869

this trend reversed because checks became more commonplace for commercial transactions and bank notes were used at a decreasing rate. State banks became increasingly more devoted to discount and deposit, and their numbers surged.

2.2 Correspondent Bank Networks

The correspondent bank networks developed during the early 1800s as a response to the geographical growth in the nation and its burgeoning population outside the industrial and populous Northeast. Correspondent banking system facilitated the inter-regional flow of funds in spite of national branching restrictions. During this period, most small rural banks maintained deposits on reserve with larger city banks which in turn cleared their checks through big city clearinghouses. In particular, New York had emerged as the preeminent correspondent banking center by the 1850s.

The National Banking Acts of 1863-1864 cemented the interconnectedness structure of U.S. banking by establishing the reserve pyramid with three distinct tiers.[5] The top tier consisted of banks which were located in central reserve cities and required to hold a 25% specie reserve on deposits.[6] Central reserve city banks had to keep all their reserves in their vault. The middle

[5]Reserve requirements were established to limit the ability of national banks to expand deposits Siegel (2014).

[6]New York City was designated as the only central reserve city in the original act, but Chicago and St. Louis were added to the list in 1887.

tier of banks, the reserve city banks, were required to hold a 25% reserve on deposits.[7] They were allowed to hold one-half of the 25% as deposits with a correspondent bank in a central reserve city with the rest in cash. Lastly, the bottom tier banks of the pyramid, known as country banks, were required to hold a 15% reserve on deposits. They could keep three-fifths of the 15% as deposits with a correspondent bank in a reserve or central reserve city with the rest in their vault.[8]

The structure of reserve requirements was considered as a source of instability in the U.S. banking system. Banks often held the maximum amount of reserves in reserve city and central reserve city banks to earn 5% interest rate on their correspondent deposits. The reserves tended to be concentrated in New York City banks, which in turn lent extensively to investors to purchase stock on margin (call loans).

2.3 Bank Panics of the National Banking Era

The National Banking Era, extending from 1865 until 1913, witnessed five major financial panics (Sprague (1910)). These crises caused hundreds of banks to suspend operations, constituting major disruptions of the financial system and called for the joint action by the New York Clearing House. During the three most severe crises, those of 1873, 1893, and 1907, specie was hoarded and circulated at a premium over checks drawn on banks and required the suspension of cash payment by the New York Clearing House. Efforts to eliminate these crises led to the creation of the Federal Reserve System (Calomiris and Gorton (1991)).

Conventional wisdom has attributed the source of systemic liquidity crises to the structure of reserve requirements and a seasonal flow of funds between New York and the interior, mainly at crop moving season. In this view, systemic liquidity crises originated from the bottom of the pyramid and spread to the top of the pyramid. This occurs as interior banks withdrew their interbank balances from reserve city and central reserve city banks in a time of monetary stringency or panic, causing a drain on the reserves of central reserve city.[9] The withdrawal

[7] There were 18 reserve cities at the time of the original act.

[8] The original act required banks to hold reserves on national bank note circulation and deposits. However, the Act of June 20, 1874 repealed reserve requirements on national bank note circulation while maintaining reserve requirements on deposits according to the above three tiers. The 5% bank note redemption fund established by this act was declared to count toward satisfying legal reserve requirements.

[9] Systemic liquidity crises tended to occur in spring and fall. Country banks needed currency in spring because of costs related to the purchases of farming implements, whereas in the late summer and early fall, withdrew their bankers balances due to costs related to harvest.

of funds by country banks reduced the reserve position of New York City banks as well as the collateral backing of call loans issued off the deposits from outside banks. The pyramiding of reserves and the heavy withdrawal of funds, especially in spring and fall, meant that the money supply tended to contract in those periods when it was needed to expand the most. Seasonal money demand and "the perverse elasticity of the money supply" have been considered an important source of the financial crises of the National Banking Era.

In addition, unexpected financial shocks in New York City were also an important source of systemic liquidity crises. The National Banking Act created "systemically important banks" in financial centers, which were large in size and highly connected. Financial shocks in New York City accompanied sharp spikes in the call money market rate and a curtailment in credit availability. The New York Clearing House attempted to mitigate shocks by mutating bank-specific information and issuing loan certificates to conserve the cash of the member banks and to deter loan contraction. In addition, during more severe panics, it suspended cash payment.

Four out of five major panics occurred with initial failure in New York City. In particular, the suspension of cash payment, which was carried out during the panics of 1873 and 1907, restricted depositor access to their funds, disabled non-financial businesses to meet payrolls, and created a currency premium. In contrast, the panic of 1893 was unique because its origin was in the interior and from there spread to New York City.

The consensus among financial historians has been that the pyramiding of reserves in New York increased the vulnerability of the U.S. banking system to systemic liquidity crises as unexpected large demands for currency in the countryside due to seasonal demands during the drop moving season. Recently, however, this view has been challenged as scholars emphasize the importance of liquidity shocks from New York City. (Wicker (2000)). This might be because reserve and central reserve city banks accumulated cash reserves to offset liquidity demands in anticipation of shocks from the interior, whereas they could not implement preventive measures to counteract unanticipated shocks in New York City. In Section 4, we compare the resilience of the banking system to both types of liquidity shocks before and after the National Banking Acts and examine whether the structure of bank networks after the Acts was more prone to systemic liquidity crises.

3 Data and Summary Statistics

We use various data sources to study the impact of the National Banking Acts on the banking sector. The first source is the *Reports of the Several Banks and Savings Institutions of Pennsylvania*, which provides quarterly balance sheets for all state banks and savings institutions. The second source is the National Bank Examination Reports, which were filed by the National Bank examiners after their annual examinations. Third, we use *Merchants & Bankers Almanac* to match bank names across the two time periods since many state banks became national banks and changed their names.

We retrieve both standard bank balance sheet information and detailed correspondent bank information from these records.[10] For state-charted banks, we have information on "due-froms" on a debtor bank-by-debtor bank basis for each bank for November of each year.[11] For national banks, we have information on interbank balances at their approved reserve agents. By combining these two types of records, we constructed a dataset consisting of the amounts due by individual debtor to each state-chartered bank and the amounts due by reserve agents to each national bank in the sample for each of the years 1862 and 1867.[12]

We choose the periods 1862 and 1867 because we wanted to capture the structure of bank networks before and after the enactment of the National Banking Act. The data for 1862 only contains state banks and captures bank behavior before the unanticipated shock of the Civil War and the following passage of the National Banking Act. In contrast, the data for 1867 contains both state and national banks. We chose the year of 1867 for two reasons. First, in the absence of deposit insurance, finding reliable correspondent banks may have been time consuming for both converted and newly established national banks, so these banks in turn may have held cash in the beginning of their operation. Hence, we wanted to give banks time to establish a correspondent relationship, but still create a sample that includes national banks that used to

[10] A sample data of the balance sheet information and intensity of linkages is provided in the Appendix, see Figure 9 and Figure 10.

[11] For state banks, we have information on insolvent debtor banks. However, we omit this information since such observations did not involve relationships between active banks.

[12] We have state bank balance sheets for the years of 1862 and 1867 and national bank balance sheets for 1867. Due to the difference in reported items between state bank balance sheets and national bank balance sheets, we standardized and created 6 asset categories and 6 liability categories. Asset categories are cash, liquid securities, illiquid securities (U.S. bonds deposited with Treasurers of U.S. to secure circulation and deposits), due from other banks, loans, and other assets. Liability categories are capital, surplus and profits, bank notes, deposits, due to other banks, and other liabilities.

be state banks in 1862. In addition, national examiners reports do not provide information on national banks reserve agents until 1867.

3.1 Balance Sheet Information

Table 2 shows the composition of bank balance sheets for Philadelphia banks, Pittsburgh banks, and country banks in 1862 and 1867. Before the National Banking Act, banks held a large amount of liquid assets. They had on average 14% of cash assets against total assets. In addition, they held large securities and interbank deposits. After the National Banking Act, the composition of bank assets changed due to the introduction of reserve requirements. The amount of liquid assets decreased due to the reduction in the amount of liquid securities. This is because U.S. bonds used to secure bank notes and deposits for national banks were considered as illiquid assets. Philadelphia banks increased cash assets, but Pittsburgh banks decreased cash assets. This might be because Philadelphia banks acted more like "central reserve city" banks although both Philadelphia and Pittsburgh banks were both classified as reserve city banks.

Table 2. SUMMARY STATISTICS

	New York			*Philadelphia*			*Pittsburgh*			*Country Banks*		
Year = 1862	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets												
Cash	22	0.189	0.085	20	0.213	0.101	7	0.181	0.064	63	0.115	0.068
Liquid Securities	22	0.157	0.142	20	0.304	0.144	7	0.317	0.125	63	0.182	0.135
Due from other banks	22	0.040	0.020	20	0.034	0.042	7	0.121	0.043	63	0.182	0.095
Loans	22	0.576	0.173	20	0.402	0.118	7	0.359	0.118	63	0.494	0.121
Against Total Liabilities												
Equity	22	0.353	0.074	20	0.240	0.055	7	0.363	0.071	63	0.282	0.091
Bank notes	22	0.038	0.029	20	0.133	0.096	7	0.391	0.173	63	0.404	0.213
Deposits	22	0.434	0.130	20	0.513	0.091	7	0.228	0.117	63	0.274	0.196
Due to other banks	22	0.125	0.106	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	Obs	Mean	SD
Against Total Assets												
Cash	19	0.376	0.151	24	0.309	0.075	15	0.123	0.066	132	0.144	0.062
Liquid Securities	19	0.055	0.104	24	0.077	0.099	15	0.083	0.141	132	0.087	0.116
Due from other banks	19	0.041	0.040	24	0.069	0.054	15	0.087	0.051	132	0.145	0.089
Loans	19	0.385	0.129	24	0.500	0.080	15	0.655	0.090	132	0.580	0.143
Against Total Liabilities												
Equity	19	0.247	0.112	24	0.298	0.075	15	0.421	0.143	132	0.375	0.102
Bank notes	19	0.093	0.047	24	0.152	0.071	15	0.213	0.120	132	0.255	0.098
Deposits	19	0.464	0.172	24	0.479	0.115	15	0.347	0.205	132	0.337	0.162
Due to other banks	19	0.193	0.171	24	0.060	0.076	15	0.018	0.031	132	0.026	0.034

Note: This table is based on authors' calculations. Equity = Capital + surplus and profits. Since illiquid securities are composed of U.S. bonds deposited with the U.S. Treasury. (1) to secure circulation and (2) to secure deposits, the category is only available for national banks. Hence, we do not include information in this table.

Table 3. Distribution of Interbank Deposits

	Philadelphia			Pittsburgh			Country Banks		
Year = 1862	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets									
New York City	16	0.398	0.251	7	0.681	0.137	51	0.314	0.309
Philadelphia	15	0.095	0.149	7	0.213	0.143	61	0.551	0.305
Pittsburgh	4	0.016	0.018	1	0.010	-	19	0.057	0.082
Other PA	19	0.234	0.115	5	0.069	0.121	53	0.147	0.213
Other U.S.	19	0.341	0.228	7	0.054	0.050	32	0.113	0.156
Year = 1867	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Interbank Deposits									
New York City	24	0.290	0.286	13	0.666	0.264	51	0.424	0.319
Philadelphia	0	-	-	4	0.444	0.338	84	0.451	0.340
Pittsburgh	0	-	-	1	1.000	-	16	0.476	0.337
Other PA	0	-	-	0	-	-	8	0.312	0.301
Other U.S.	0	-	-	1	0.002	-	9	0.274	0.358

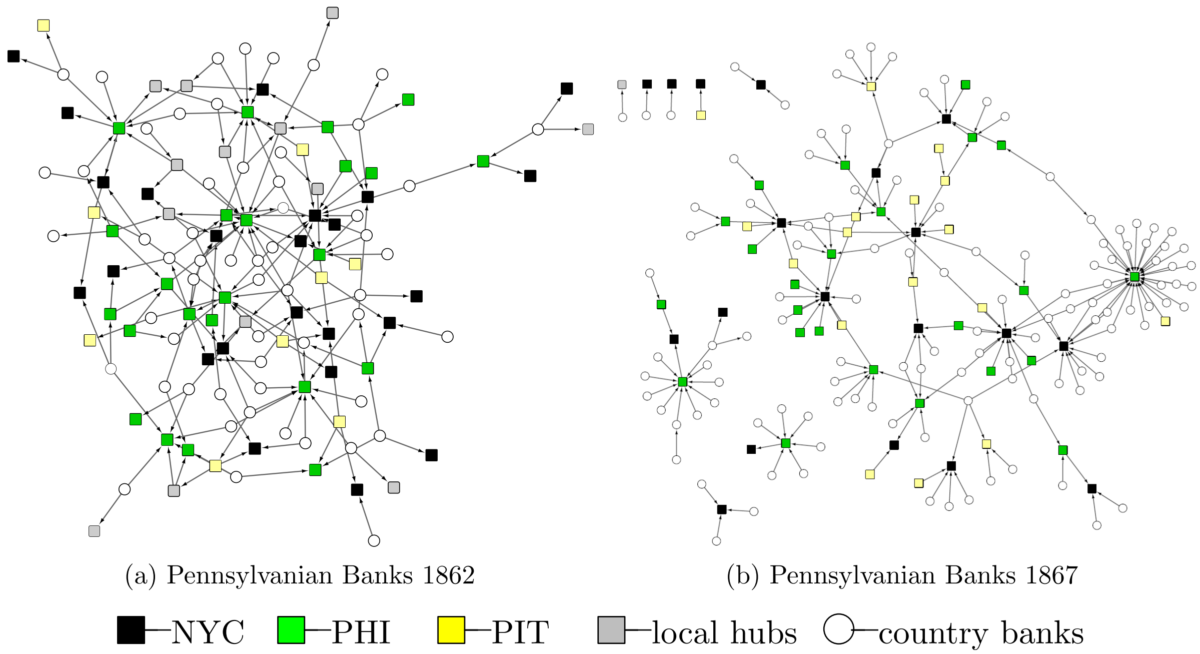
Notes: This table shows the proportion of major deposits of the banks to banks in New York City, Philadelphia, Pittsburgh, Other PA including cities and towns in Pennsylvania except for Philadelphia and Pittsburgh, and Other U.S. includes all the other towns outside Pennsylvania and New York City. The table shows before the National Banking Actm in 1862, Philadelphia and Pittsburgh banks had most of their interbank deposits in New York City banks. In contrast, country banks had a large portion of their deposits in Philadelphia banks. After the National Banking Act, in 1867, Philadelphia banks decreased the amount of interbank deposits in New York City, but country banks increased the amount of interbank deposits in New York City and Pittsburgh.

Additionally, the reserve requirement of the National Banking Act shifted the selection of where large deposits of the bank were sent. Table 3 shows the distribution of interbank deposits. Before the National Banking Act, Philadelphia and Pittsburgh banks had most of their interbank deposits in New York City banks. In contrast, country banks had a large portion of their deposits in Philadelphia banks. After the National Banking Act, Philadelphia banks decreased the amount of interbank deposits in New York City, but country banks increased the amount of interbank deposits in New York City and Pittsburgh.

3.2 Correspondent Networks

The National Banking era saw a three-tied and much more centralized reserve deposit network structure compared to that of 1862. Figure 1 visualizes the bank networks in 1862 and 1867 at the bank level. Before the National Banking era, the network in 1862 demonstrates a core-periphery structure. A small number of highly connected New York City banks mainly received

Figure 1. Bank Major Deposit Network

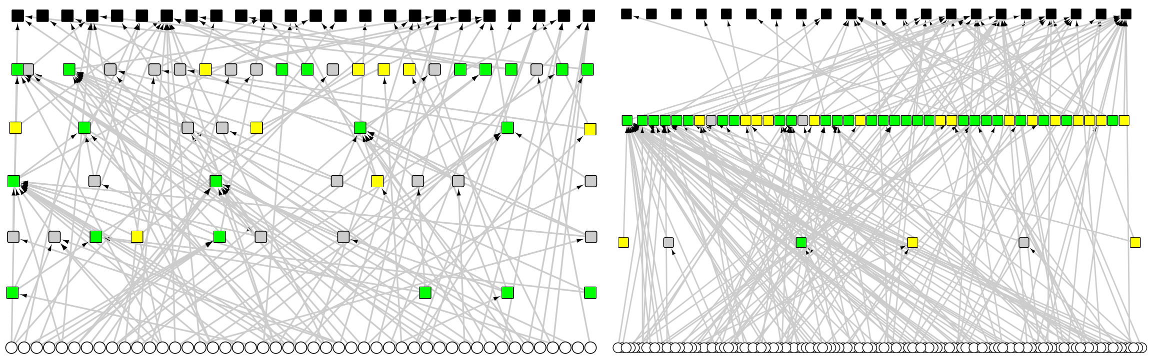


(a) Pennsylvanian Banks 1862 (b) Pennsylvanian Banks 1867

Note: This figure visualizes the bank reserve deposit networks in 1862 and 1867. The nodes colored in black, green, yellow, gray, and white denote respectively banks located in New York City, Philadelphia, Pittsburgh, other local hubs, and counties. A link with an arrow indicates a recorded reserve deposit relationship where the arrow points to the deposit receiver.

reserve deposits; A large number of country banks were in the periphery mainly acting as depositors; Another group of banks in reserve cities were interconnected in the middle of the reserve deposit chain, receiving and depositing reserves at the same time. This core-periphery structure is typical of banking networks even in the modern financial system as seen by Santos and Cont (2010) for the Brazilian interbank networks, Martinez-Jaramillo, Alexandrova-Kabadjova, Bravo-Benitez, and Solórzano-Margain (2014) for the Mexican banking system, as well as Craig and von Peter (2014) for the German banking system. This structure is also more generally observed in other financial payment systems (Inaoka, Ninomiya, Taniguchi, Shimizu, and Takayasu (2004), Soramäki, Bech, Arnold, Glass, and Beyeler (2007), Bech and Atalay (2010)) and dealer networks (Li and Schrhoff (2014) and Hollifield, Neklyudov, and Spatt (2014)). While the majority of the deposits were sent by the country banks to core banks in New York City, Philadelphia, and Pittsburgh, there was also a proportion of reserves put to local transportation and money

Figure 2. Concentration of Tiers in Bank Deposit Network



(a) Pennsylvanian Cities 1862 (b) Pennsylvanian Cities 1867

NYC PHI PIT local hubs country banks

Note: This figure visualizes the bank reserve deposit networks in 1862 and 1867 with hierarchical directed network structure. The nodes colored in black, green, yellow, gray, and white denote respectively banks located in New York City, Philadelphia, Pittsburgh, other local hubs, and counties. A link with an arrow indicates a recorded reserve deposit relationship where the arrow points to the deposit receiver. The tiers are constructed such that all the arrows point to upper tiers.

hubs, such as those located in Harrisburg.

After the enactment of the National Banking Act, the reserve deposit network remained its core-periphery structure. However, compared to 1862, it created a 3-tiered hierarchical structure and became more centralized. Country banks sent their major deposits now to a single reserve city bank, in Philadelphia or Pittsburgh, and the reserve city banks deposited with one to two New York City banks. The effect of the Acts is more clearly seen in the hierarchical structure of the directed reserve deposit network in Figure 2. The hierarchical structure illustrates how reserve deposit goes from the bottom tier (country banks) to the top tier (New York City banks). In 1862, the network shows multiple tiers with several local money hubs and that banks in Philadelphia and Pittsburgh deposit with each other. However, in 1867, the network transforms into a clear three-tier hierarchy: bottom tier country banks → middle tier reserve city banks in Philadelphia and Pittsburgh → top tier New York City banks. As a result, the intermediation chain of reserve deposit becomes much shorter in 1867.

Table 4 tabulates the distribution of banks by their roles in the reserve deposit network by location. We group banks by location in New York City, Philadelphia, Pittsburgh, local

Table 4. Roles in the Reserve Deposit Network by Location

	Obs	Depositor only	Deposit-taker only	Intermediary	Isolated
Year =1862					
NYC	22	0	22	0	0
Philadelphia	20	6	0	14	0
Pittsburgh	7	5	0	2	0
Harrisburg	3	0	2	1	0
Country banks	61	46	0	12	3
Year = 1867					
NYC	19	0	19	0	0
Philadelphia	28	9	0	19	0
Pittsburgh	19	11	0	8	0
Harrisburg	3	3	0	0	0
Country banks	129	125	0	4	0

Notes: This table shows the number of banks that acted as reserve depositors only, deposit-takers only, intermediaries, and isolated. "Depositor only" refers to banks that only deposit reserves to other banks, i.e. they are at the beginning of a path in a network. "Deposit-taker only" refers to banks that only take reserves from other banks, i.e. they are at the end of a path in a network. "Intermediary" refers to banks that both deposit reserves to other banks and take reserves from other banks, i.e. they are in the middle of a path in a network. "Isolated" refers to banks that are not recorded to deposit reserves or take reserves with other banks, i.e. they do not have have any vertex in the network. From 1862 to 1867, the role of banks in the deposit network became more specialized by location: more Philadelphia and Pittsburgh banks became intermediaries, whereas country banks evolved into mostly depositors only. Notably, the local hubs in 1862 such as Harrisburg banks all turned into depositor-only banks in 1867.

hubs such as Harrisburg, and other counties. Then we look at the distribution of banks that served as reserve depositors only, reserve deposits takers only, intermediaries (both receive and send deposits), as well as none of the above (isolated). NYC banks were always reserve deposit takers only. Banks in Philadelphia were most likely serving as intermediaries. The majority of country banks were depositors only. Country banks that acted as local hubs in 1862 are located in bigger townships for instance in Harrisburg, Lancaster, Reading, and York. (We tabulate banks in Harrisburg as an example.) From 1862 to 1867, the role of banks in the deposit network became more specialized by location: more Philadelphia and Pittsburgh banks became intermediaries, whereas country banks evolved into mostly pure depositors. Notably, the local hubs in 1862 such as Harrisburg banks all turned into depositor-only banks in 1867.

Table 5. Longest Shortest Path and Centrality by Location

	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
	Longest Shortest Path			Closeness Centrality			Betweenness Centrality		
Year = 1862									
NYC	0	0	0	1	1	1	0	0	0
Philadelphia	2.4	5	1	0.5	0.7	0.2	0.0035	0.0221	0
Pittsburgh	1.9	4	1	0.5	0.7	0.3	0.0001	0.0004	0
Harrisburg	1.3	4	0	0.8	1.0	0.4	0.0012	0.0035	0
Country banks	3.0	6	0	0.4	1.0	0.2	0.0004	0.0053	0
Year = 1867									
NYC	0	0	0	1	1	1	0	0	0
Philadelphia	1	1	1	0.7	0.7	0.5	0.0002	0.0015	0
Pittsburgh	1.3	3	1	0.6	0.7	0.4	0.0001	0.0002	0
Harrisburg	2	2	2	0.5	0.6	0.4	0	0	0
Country banks	1.8	3	1	0.6	0.7	0.3	0	0.0001	0

Notes: This table shows the statistics of the longest shortest path, closeness centrality, and betweenness centrality, by location and by year. We use the Floyd-Warshall algorithm to compute the shortest path between one node to another in a directed graph. Closeness centrality gives high centralities to vertices that are at a short average distance to every other reachable vertex. Betweenness centrality quantifies the number of times a node acts as a bridge along the shortest path between two other nodes. From 1862 to 1867, the length of shortest path decreased for country banks, indicating a more centralized network structure. In particular, the maximum of this statistics decreased from 6 to 3, confirming the 3-tier bank network structure. Closeness measures increased across all banks, indicating that the network structure became more centralized with shorter distance between banks. Similarly, the betweenness centrality decreases, which confirms that banks were closer to each other.

To see that the 1867 network became more concentrated, Table 5 shows evidence that the network path from reserve depositor to reserve deposit takers generally became shorter. Based on the directed deposit network, we compute the shortest path between one node to another in a directed graph using the Floyd-Warshall algorithm. Then we compute the longest shortest path for each node. In 1862, the average length of the longest shortest path starting from a country bank was 3, with the max being 6. This means that there existed one path of a reserve deposit chain which had a length of 6 connecting 7 banks. From 1862 to 1867, the length of shortest path decreased for country banks, indicating a more centralized network structure. In particular, the maximum of this statistics decreased from 6 to 3, confirming the 3-tier bank network structure.

Table 6. Degrees by Location

	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
	Degree			In-Degree			Out-Degree		
Year = 1862									
NYC	2.7	10	1	2.7	10	1	0	0	0
Philadelphia	5.5	15	1	3.4	13	0	2.1	5	1
Pittsburgh	2.3	3	1	0.3	1	0	2.0	3	1
Harrisburg	2.3	5	1	2.0	4	1	0.3	1	0
Country banks	2.0	5	0	0.2	2	0	1.7	5	0
Year = 1867									
NYC	5.4	18	1	5.4	18	1	0	0	0
Philadelphia	4.2	32	1	3.1	31	0	1.0	2	1
Pittsburgh	2.1	6	1	0.8	5	0	1.2	2	1
Harrisburg	1.3	2	1	0.0	0	0	1.3	2	1
Country banks	1.2	4	1	0.0	1	0	1.2	4	1

Notes: This table shows the statistics for total degrees, in-degree, and out-degree of the bank reserve deposit network by location and by year. The degree of a node in a network is the number of connections it has to other nodes. In-degree of a node in a network is the number of incoming edges. Out-degree of a node in a network is the number of out-going edges. From 1862 to 1867, the number of degrees of NYC significantly increased, whereas that for Harrisburg and Country banks decreased. Notably, the in-degree of Country banks including Harrisburg banks reduced to 0, while this number doubled for NYC banks. Furthermore, the out-degree of Philadelphia and Pittsburgh banks became close to 1 in 1867. All these evidence indicates that the networks became a more concentrated 3-tier structure, in which lower tier banks had one link going to upper tier banks, and that one NYC bank was linked with a much higher number of lower tier banks.

Furthermore, the closeness centrality and betweenness centrality measures reported in Table 5 speak to our observation. Closeness centrality gives high centralities to vertices that are at a short average distance to every other reachable vertex. Betweenness centrality quantifies the number of times a node acts as a bridge along the shortest path between two other nodes. These network centrality measures help to contrast balance sheet data as they suggest that "important" institutions within a network are not necessarily determined just by size (Martinez-Jaramillo, Alexandrova-Kabadjova, Bravo-Benitez, and Solórzano-Margain (2014)). From 1862 to 1867, closeness measures increased across all banks, indicating that the network structure became more centralized with shorter distance between banks. Similarly, the betweenness centrality decreased, which confirmed that banks were closer to each other and the length of paths became shorter.

Last but not least, Table 6 shows total degree numbers grouped by location, with a breakdown of in-degrees and out-degrees. The number of degrees of NYC banks increased from 1862 to 1867, whereas that for Harrisburg and Country banks decreased. Especially the in-degree of country banks including Harrisburg banks reduced to 0, while this number doubled for NYC banks. Moreover, the out-degree of Philadelphia and Pittsburgh banks became close to 1 in 1867. The above evidence together corroborates that the networks became a more concentrated 3-tier structure, in which lower tier banks have one link going to upper tier banks, and that one NYC bank is linked with a much higher number of lower tier banks.

4 Model

In this section, we describe a model of interbank reserve deposit network. Banks deposit reserves with each other, thereby creating interbank liability relationships. Shocks originating from NYC banks and country banks respectively can trigger endogenous early withdrawals and further cause contagious default. The environment extends the clearing equilibrium in Eisenberg and Noe (2001) and Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) to two periods with endogenous liquidity withdrawal and liquidation risk.

4.1 Environment

Consider a single-good economy, populated by N risk neutral banks, $i = \{1, 2, ..., N\}$. The economy lasts for two periods ($t = 0, 1, 2$) and there is no discounting. Figure 3 illustrates the model timeline.

At $t = 0$, bank i is endowed with equity capital K_i. It holds deposit D_i from households. It can also hold interbank reserve deposit from other banks. Denote the reserve deposit that bank j puts to bank i as L_{ji}; bank j is the reserve depositor and i is the reserve holder. The interbank deposit network is characterized by the N banks together with a weighted, directed graph $L = [L_{ji}]$. The total liability of bank i amounts to $D_i + \sum_j L_{ji}$. The liability is demand deposit with maturity of two periods but can be withdrawn early at $t = 1$. The early withdrawal decisions will be introduced in the next subsection. The total asset is allocated as vault cash C_i, loan investment I_i, and reserve deposits in other banks $\sum_k L_{ik}$. The bank balance sheet items

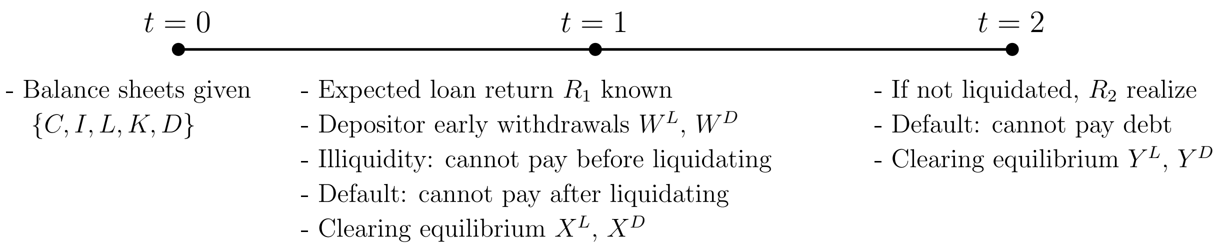


Figure 3. Model Timeline

at the initial date are summarized in in the following table.

Table 5. BALANCE SHEET OF BANK i AT $t = 0$

Asset	**Liability**
Vault cash C_i	Equity capital K_i
Loan I_i	Deposit D_i
Due-from $\sum_k L_{ik}$	Due-to $\sum_j L_{ji}$

Equation: $C_i + I_i + \sum_k L_{ik} = K_i + D_i + \sum_j L_{ji}$

Bank i's loan investment matures at the final date $t = 2$ with return rate $R_{i,2}$. Hence, the cash flow from loan investment at $t = 2$ amounts to $I_i R_{i,2}$. Loan investment is risky. $R_{i,2}$ follows

$$\log R_{i,1} = \log R_{i,0} + \varepsilon_{i,1}, \tag{1}$$

$$\log R_{i,2} = \log R_{i,1} + \varepsilon_{i,2}, \tag{2}$$

where the idiosyncratic shocks ε_t realize at time t. The vector ε_t is normally distributed with mean ν_t, standard deviation σ_t, and correlation matrix ϱ_t.[13] Here, the loan returns are bounded below by 0 so banks can lose up to their initial investment. The investment returns are potentially correlated among banks. This allows us to account for the correlated investments, such as the common securities pool held by NYC banks as well as the common shocks to geographically proximate country banks during crop-moving season.

[13] Nier, Yang, Yorulmazer, and Alentorn (2007) argue that idiosyncratic shocks are a cleaner starting point for studying contagion effect due to interbank exposures and liquidity effects. In our quantitative analysis, we will start from $\varrho = 0$, and then vary ϱ for robustness.

4.2 Early Deposit Withdrawal

Early withdrawals by households and bank depositors can potentially trigger illiquidity event, which could further cause default. Whether bank i is able to meet early withdrawals depends on the amount of withdrawals, the level of cash holding, and whether other banks are able to return their reserves on demand. Denote the interbank clearing payment matrix at $t = 1$ as X^L where X^L_{ik} denotes the payment by bank k upon bank i's early withdrawal, $X^L_{ik} \in [0, L_{ik}]$. Similarly, let X^D be the payment vector to household depositors' early withdrawals, $X^D \in [0, D]$.

Next we define the early withdrawal events W^L and W^D. Indicator $W^L_{ik} = 1$ denotes that bank i withdraws reserve deposit L_{ik} from k at $t = 1$. Similar notation holds for W^D. The early withdrawal events are endogenous in the model. Early withdrawals occur when *any of the following condition holds.*

(A) The reserve holder has low expected return and high default likelihood. If conditional on $R_{i,1}$, the probability of bank i defaulting at final date exceeds a threshold $\bar{p}$, all of bank i's depositors withdraw.

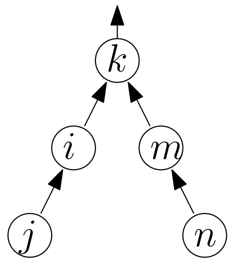
$$\Pr\left(C_i + I_i R_{i,2} + \sum_k L_{ik} < D_i + \sum_j L_{ji} \mid R_{i,1}\right) > \bar{p} \Rightarrow W^L_{ji} = 1, \forall L_{ji} > 0;\ W^D_i = 1. \tag{3}$$

(B) The depositor bank itself has liquidity shortage. When bank i experiences early withdrawals by its own depositors and the cash holding C_i cannot cover the liquidity need, bank i withdraws its reserves.

$$C_i < \sum_j W^L_{ji} L_{ji} + W^D_i D_i \Rightarrow W^L_{ik} = 1, \forall L_{ik} > 0. \tag{4}$$

(C) The reserve holder cannot recover its own deposit in full When bank i's holder bank k defaults on i's reserve, bank i may not be able to repay deposits in full. In this case, depositors of bank i tend to withdraw.

$$\sum_k W^L_{ik} X^L_{ik} < \sum_k W^L_{ik} L_{ik} \Rightarrow W^L_{ji} = 1, \forall L^L_{ji} > 0;\ W^D_i = 1. \tag{5}$$



i withdraws from k when

- i experiences withdrawal from j
- k has low $R_{k,1}$ and high default likelihood
- k's other depositor m withdraws
- k's holder defaults

Top-to-bottom Crises

- Shock to $R_{k,1}$
- i and m withdraw
- k's household depositors withdraw
- k liquidates and defaults
- j and n withdraws from i and m.
- i and m liquidate and default, etc...

Bottom-to-top Crises

- Shock to W_j^D and W_n^D
- j and n withdraw from i and m
- i and m withdraw from k
- k's household depositors withdraw
- k liquidates and defaults
- i and m liquidate and default, etc...

Figure 4. Liquidity Withdrawal This figure illustrates the events that can trigger early withdrawals. It also explains how top-to-bottom and bottom-to-top crises are modeled.

(D) Other depositors withdraw from the reserve holder. From the bank run literature, if there exist depositors of bank i withdraw, then all other depositors of bank i tend to withdraw.

$$\sum_j W_{ji}^L L_{ji} + W_i^D D_i > 0 \Rightarrow W_{ji}^L = 1, \forall L_{ji} > 0;\ W_i^D = 1. \tag{6}$$

These events that trigger early withdrawals are summarized in Figure 4. Under such endogenous liquidity withdrawal framework, as long as one of bank i's depositors withdraws, all of the depositors will withdraw simultaneously, causing illiquidity. Event (A) is withdrawal caused by fundamental shocks; events (B) and (C) are vertically contagious withdrawals; event (D) is horizontally contagious withdrawal.

4.3 Early Withdrawal Payment Equilibrium

When the liquidity at hand cannot cover early withdrawals, costly liquidation occurs. Next we define respectively the events of *illiquidity* and *default* at $t = 1$ based on whether a bank has enough liquidity to pay back debt before and after liquidating loan investments.

Definition 1 *Bank i incurs illiquidity at $t = 1$, denoted by $\mathbb{I}_i^l$, when after withdrawing all reserve* *deposits held by other banks, bank i still cannot pay back early withdrawals, i.e.*

$$\mathbb{I}_i^l = 1 := C_i + \sum_k W_{ik}^L X_{ik}^L < \sum_j W_{ji}^L L_{ji} + W_i^D D_i. \tag{7}$$

In such an event, bank i liquidates loan investment at a proportional cost of $\xi_l \in (0, 1)$, yielding $I_i(1 - \xi_l)$

Accounting for potential liquidation, the total cash flow of bank i equals the sum of vault cash, total payments received from other banks, and liquidation yields if applies. The total cash flow is

$$H_i^1 = C_i + \sum_k W_{ik}^L X_{ik}^L + \mathbb{I}_i^l I_i(1 - \xi_l). \tag{8}$$

If the total cash flow is greater or equal to the total early withdrawal, bank i pays the total nominal debt in full. The bank obtains the remaining cash as equity if the loan has been liquidated; if else, the bank obtains the investment return at maturity. However, if the total cash flow is smaller than total early withdrawal even after liquidation, bank i *defaults.*

Definition 2 *Bank i has early default at $t = 1$, denoted by $\mathbb{I}_i^{d1}$, when the total cash flow is smaller than its early withdrawals, i.e.,*

$$\mathbb{I}_i^{d1} = 1 := H_i^1 < \sum_j W_{ji}^L L_{ji} + W_i^D D_i. \tag{9}$$

In such an event, a social cost due to default is incurred proportional to the cash shortfall, that is $\mathbb{I}_i^{d1} \xi_d \left(\sum_j W_{ji}^L L_{ji} + W_i^D D_i - H_i^1 \right)$, $\xi_d > 1$. This approach follows Glasserman and Young (2015b) and captures the fact that large shortfalls are considerably more costly than small shortfalls, where the firm nearly escapes bankruptcy. When $\xi_d > 1$, each dollar of payment shortfall would create an additional $\xi_d - 1$ dollars in bankruptcy costs, above and beyond the shortfall itself.[14]

The defaulting bank pays all depositors on a *pro rata* basis, resulting in zero equity value. In the modern banking system household depositors have seniority in payment priority; however

[14] The default cost can result from loss of bank franchise value and disruption of credit and payment services to local customers and businesses, see, for example White and Yorulmazer (2014). The default cost of failing banks is partly financed by the bank shareholders under the double liability rule - a form of contingent liability requirement imposed by the National Banking Acts. Under double liability, shareholders of failing banks could lose not only the market value of the equity, but also the par value. For details on double liability see Esty (1998) and Grossman (2001).

in the National Banking Era, household depositors have the same seniority as bank reserve depositors.[15] Essentially, household depositors and all reserve depositing banks are paid by the defaulting bank in proportion to the size of their nominal claims on the bank's assets. The payment matrix at $t = 1$ is given by

$$X_{ji}^L = \frac{W_{ji}^L L_{ji}}{\sum_j W_{ji}^L L_{ji} + W_i^D D_i} \left[\min \left\{ \sum_j W_{ji}^L L_{ji} + W_i^D D_i, H_i^1 \right\} \right]^+, \tag{10}$$

where $[\cdot]^+ = \max\{\cdot, 0\}$ and guarantees that depositors do not incur further payment when holder defaults. Similarly, payment to household depositors X_i^D is given by

$$X_i^D = \frac{W_i^D D_i}{\sum_j W_{ji}^L L_{ji} + W_i^D D_i} \left[\min \left\{ \sum_j W_{ji}^L L_{ji} + W_i^D D_i, H_i^1 \right\} \right]^+. \tag{11}$$

Definition 3 *Given balance sheet $\{C, I, K, D, L\}$, expected loan returns R_1, withdrawal indicators W^L and W^D defined by (3) - (6), illiquidity and default indicators $\mathbb{I}^l$ and $\mathbb{I}^{d1}$ defined by (7) - (9), the collection of interbank reserve deposit payment X^L together with the household deposit payment X^D defined by (10) - (11) form an* early withdrawal payment equilibrium *of the bank deposit network at $t = 1$.*

Following Eisenberg and Noe (2001) and Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), we can further show that such a payment equilibrium characterized by matrix X^L and vector X^D always exists and is generically unique.

Proposition 1 *For any given (C, I, K, D, L, R_1), an early withdrawal payment equilibrium $\{X^{L^*}, X^{D^*}\}$ at $t = 1$ always exists and is generically unique.*

4.4 Final Date Payment Equilibrium

The final date payment system consists of all banks that have experienced no early withdrawals from depositors. For any bank i in this final date system, all its depositors must also be in the system, whereas its reserve holders could either be in the system or have liquidated but not defaulted. Whether bank i is able to deliver the full amount of its matured obligations depends on the level of its cash holding, loan investment return, and whether other banks are

[15] Seniority refers to the order of repayment in the event of bankruptcy. Senior debts are repaid first during bankruptcy.

able to return its reserve deposits. Denote the interbank clearing payment matrix at $t = 2$ as Y^L where Y^L_{ik} denotes the payment by bank k, $Y^L_{ik} \in [0, L_{ik}]$. If $Y^L_{ik} < L_{ik}$, bank k defaults on deposits to bank i. Similarly let Y^D be the payment vector to household depositors at maturity, $Y^D \in [0, D]$.

The final date default event is defined based on whether a bank is able to pay back debt obligations using all assets. The total cash flow at the final date is

$$H_i^2 = C_i + I_i R_{i,2} + \sum_k \left(W^L_{ik} X^L_{ik} + (1 - W^L_{ik}) Y^L_{ik} \right). \tag{12}$$

Definition 4 *For a bank i that experiences no early withdrawals $\sum_j W^L_{ji} L_{ji} + W^D_i D_i = 0$, it defaults at $t = 2$, denoted by $\mathbb{I}^{d2}_i$, when the total cash flow is smaller than nominal debt obligation,*

$$\mathbb{I}^{d2}_i = 1 := H_i^2 < \sum_j L_{ji} + D_i. \tag{13}$$

In such an event, a social cost due to default is incurred proportional to the cash shortfall.

The defaulting bank pays all depositors on a *pro rata* basis, resulting in zero equity value. The interbank payment matrix and household deposit payment vector at $t = 2$ are respectively

$$Y^L_{ji} = \frac{L_{ji}}{\sum_j L_{ji} + D_i} \left[\min \left\{ \sum_j L_{ji} + D_i, H_i^2 \right\} \right]^+, \tag{14}$$

$$Y^D_i = \frac{D_i}{\sum_j L_{ji} + D_i} \left[\min \left\{ \sum_j L_{ji} + D_i, H_i^2 \right\} \right]^+. \tag{15}$$

Definition 5 *Given balance sheet $\{C, I, K, D, L\}$, realized loan returns R_2, withdrawal indicators W^L and W^D defined by (3) - (6), illiquidity and early default indicators $\mathbb{I}^l$ and $\mathbb{I}^{d1}$ defined by (7) - (9), early withdrawal payment equilibrium X^L and X^D defined by (10) - (11), and final date default indicators $\mathbb{I}^{d2}$ by (12) - (13), the collection of interbank reserve deposit payment Y^L and household deposit payment Y^D given by (14) - (15) together with the remaining banks form a* final date payment equilibrium *of the bank deposit network at $t = 2$.*

Similarly, we can show that such a payment equilibrium characterized by matrix Y^L and vector Y^D always exists and is generically unique.

5 Quantitative Analysis

In this section, we quantitatively examine the effect of bank network structure on financial stability. We use the empirically observed bank networks and bank balance sheets in 1862 and 1867 and quantify how such a change in L affects the resilience of the interbank system.

Abstracting from the key features of the five banking crises occurred in the National Banking Era, we simulate two classes of banking crises: the top-to-bottom crises and bottom-to-top crises. These two classes of crises are simulated based on the types and origins of negative shocks we feed into the system.

For the top-to-bottom crises, the New York City banks receives negative fundamental shocks due to low expected loan investment returns; This potentially causes illiquidity from the top of the hierarchical network. For the bottom-to-top crises, country banks experience negative liquidity shocks as households (farmers) withdrawal depositor early. This triggers illiquidity from the bottom of the hierarchical network.

Depending on the network structure, illiquidity may spread to banks in other parts of the system differently. We want to quantify such effect. Using Monte Carlo simulations, we calculate a broad set of measures of financial stability. These measures include (1) systemic risk, measured by the probability of joint liquidation and joint default events and the expected percentage of bank liquidation and default; (2) welfare loss, the expected percentage value loss from liquidation and default; and (3) contagion risk, the percentage of bank liquidation and default caused by the default of a counterparty hit with direct negative shocks.

5.1 Constructing Banking Systems Using Real Data

We obtain the values of balance sheet items (C, I, K, D, L) from individual bank balance sheet data for the years of 1862 and 1867. As described in Section 3, we compute cash, the vector C, by summing up the balance sheet items *cash* and *liquid securities*.[16] Equity capital, K, equals *bank capital* plus *profits and earnings*. Deposit, D, is constructed by adding *deposits* and *bank notes*. Bank reserve network L is taken as in the data where L_{ij} is the dollar value of reserve deposits by bank i to bank j. Finally, we back out the level of loan investments, I, from

[16] For 1862, securities are not required to be put up as collateral, so we categorize all securities as liquid.

the balance sheet equation, i.e.,

$$\text{Loans} = \text{Equity} + \text{Deposits} + \text{Due to other banks} - \text{Cash} - \text{Due from other banks}, \tag{16}$$

where *"Due to other banks"* is the total interbank deposits and *"Due from other banks"* is the total interbank reserves held by other banks.

We parametrize the remaining model parameters, $\{\xi_l, \xi_d, \nu_t, \sigma_t, \varrho_t, \bar{p}\}$. The liquidation and default cost ξ_l and ξ_d are scalers for the total costs. Therefore, when comparing across years under the same scalers, the particular values do not matter. In the simulation, we will set as benchmark $\xi_l = 50\%$ and $\xi_d = 150\%$. This means that when in an asset liquidation, 50% of the illiquid asset value can be converted to cash. When an institution defaults, each dollar of payment shortfall would create an additional 50% dollars in bankruptcy costs, above and beyond the shortfall itself.[17] The baseline distribution of loan investment return rate has $N(\nu_1 = 0, \sigma_1 = 0.1, \varrho_1 = 0)$, $N(\nu_2 = 0, \sigma_2 = 0.1, \varrho_2 = 0)$. The values are chosen similarly to Georg (2013). We vary these parameter values in the comparative statics. Also in the top-to-bottom crises, we lower the ν_1 for the New York City banks. Finally, for $\bar{p}$, the threshold of expected default probability to trigger depositor early withdrawals, we set the benchmark value to 10% and check for robustness.

5.2 Measures of Financial Stability

To quantify the impact of network structure on financial stability, we need appropriate measures for the resilience of the financial system. Prior literature appears to have not yet agreed upon the definitions of systemic risk. Eisenberg and Noe (2001) propose measuring the chances of waves of default (joint default events) that a given shock induces in a network. Acharya, Pedersen, Philippon, and Richardson (2009) define it as "the risk of a crisis in the financial sector and its spillover to the economy at large." De Bandt and Hartmann (2000) consider systemic risk as "a systemic event that affects a considerable number of financial institutions or markets in a strong sense, thereby severely impairing the general well-functioning of the financial system." Glasserman and Young (2015a) calculate the total loss in value summing over all notes in the system. Other research has used market-based measures such as marginal expected short-

[17] These values are set following Glasserman and Young (2015b).

fall (Acharya, Engle, and Richardson (2012)), liquidity mismatch index (Brunnermeier, Gorton, and Krishnamurthy (2014)), CoVaR (Adrian and Brunnermeier (2011)), and etc.

Here we do not take a stand on what the best measures should be. Instead, we calculate and present a broad set of statistics as indicators of financial stability. The first set of measures focuses on systemic risk of bank liquidation and defaults. We compute $\mathbb{P}_l^{joint}$, the probability of joint bank liquidation when there are more than θ_l fraction of banks liquidating simultaneously. We also compute the probability of joint default at $t = 1$ and $t = 2$ when there are more than θ_d fraction of banks defaulting simultaneously, $\mathbb{P}_{d1}^{joint}$ and $\mathbb{P}_{d2}^{joint}$.

$$\mathbb{P}_l^{joint} = \mathbb{P}\left(\frac{\sum_i \mathbb{I}_i^l}{N} \geq \theta_l\right), \quad \mathbb{P}_{d1}^{joint} = \mathbb{P}\left(\frac{\sum_i \mathbb{I}_i^{d1}}{N} \geq \theta_d\right), \quad \mathbb{P}_{d2}^{joint} = \mathbb{P}\left(\frac{\sum_i \mathbb{I}_i^{d2}}{N} \geq \theta_d\right). \tag{17}$$

Without loss of generality, we consider the threshold for a systemic liquidation event to be $\theta_l = 20\%$ of all banks, and the threshold for a systemic default event to be $\theta_d = 20\%$ of all banks.[18]

The second set of measures look at the expected percentage of banks liquidating, early defaulting, and late defaulting, denoted by respectively P_l, P_{d1}, and P_{d2}.

$$P_l = \mathbb{E}\left(\frac{\sum_i \mathbb{I}_i^l}{N}\right), \quad P_{d1} = \mathbb{E}\left(\frac{\sum_i \mathbb{I}_i^{d1}}{N}\right), \quad P_{d2} = \mathbb{E}\left(\frac{\sum_i \mathbb{I}_i^{d2}}{N}\right). \tag{18}$$

Next we consider the magnitude of dollar cost incurred due to either bank liquidation or default events. V_l denotes the expected dollar value of total liquidation costs normalized by the total value of bank balance sheets. Similarly, V_{d1} and V_{d2} denote respectively the expected dollar costs due to early default and final date default as a percentage of total value of bank balance sheets of that year. The formulas are specified as follows,

$$V_1 = \frac{\mathbb{E}\left[\sum_i \mathbb{I}_i^l \xi_1 I_i\right]}{\sum_i \left(K_i + D_i + \sum_j L_{ji}\right)}. \tag{19}$$

$$V_{d1} = \frac{\mathbb{E}\left[\sum_i \mathbb{I}_i^{d1} \xi_d \left(D_i + \sum_j L_{ji} - H_i^1\right)\right]}{\sum_i \left(K_i + D_i + \sum_j L_{ji}\right)}, \quad V_{d2} = \frac{\mathbb{E}\left[\sum_i \mathbb{I}_i^{d2} \xi_d \left(D_i + \sum_j L_{ji} - H_i^2\right)\right]}{\sum_i \left(K_i + D_i + \sum_j L_{ji}\right)}. \tag{20}$$

Lastly, we are interested in measuring contagion risk. For this, we look at the percentage of

[18] The parameterization of the systemic liquidation and default threshold is without loss of generality. The probabilities will be higher if we set a lower fraction. The θ_l value is set so that the systemic risk in different crises simulations is not too low and not too high. In Gai and Kapadia (2010) for example they set the fraction as 5%.

liquidating and defaulting banks which are not directly shocked themselves but whose counterparties are negatively shocked. In particular, we compute the fraction of bank liquidations and defaults minus the fraction of banks negatively shocked.

5.3 Top-to-bottom Crises

As discussed in Section 2.3, top-to-bottom crises occurred when liquidity shocks hit banks in New York City and spread to the rest of the system. In the simulation, we shock all the NYC banks with lower expected loan return rate by reducing ν_1 of all or part of the NYC banks. We then plug in the balance sheet data and the linkage matrix empirically observed in 1862 and 1867 and compare the financial stability measures across the years of 1862 and 1867. Quantitative results show that the role of the bank network structure depends crucially on the aggregate condition.

Low aggregate risk

We consider the aggregate risk to be low when for all banks that are not directly shocked in the loan investment rate, the expected loan investment return rate is not very low, and the return rate volatility is not very large. In this case, we find that the 1867 bank network is more robust when negative shocks originate from the NYC banks, regardless of the type (shocks to $\bar{e}$ or σ_e) or the size of shocks.

Specifically, we consider the baseline distribution with $\bar{e} = 0$, $\sigma_e = 0.05$ for all banks. Then we shock the NYC banks by increasing σ_e from the baseline level 0.05 by up to 0.5 for all NYC banks.[19] In Figure 5, Panels a and b, we plot the systemic risk measures, $\mathbb{P}_l^{joint}$ and $\mathbb{P}_d^{joint}$ as in equation (17), against σ_e on the horizontal axis. The black solid curves plot the systemic risk measure before the Acts (1862) and the red dashed curves stand for after the Acts (1867). As the NYC banks experience high liquidity risk caused by the loan return rate volatility, systemic risk increases in both years. However, compared to the pre-Actsbanking system in 1862, the post-Acts (1867) network has much lower likelihood of joint liquidation and default, indicating that the bank network becomes more robust.

[19] The exact size of the volatility shock that occurred to NYC banks during the historical banking crises is an empirical question and is out of the scope of our paper. Rather, we look at a panel of NYC banks in 1872 - 1875 and compute their loan returns as the sum of profit and surplus divided by the loan size every year. For each bank, we compute the standard deviation of loan returns over the four years. The average of the loan returns standard deviation among banks is 3% and the maximize reaches 14% - 15%.

Figure 5, Panels c and d, plot the systemic risk measures, P_l and P_d in equation (18), against σ_e of the shocked NYC banks. As the NYC banks experience high liquidity risk generated by the loan return rate volatility, the post-Acts (1867) network experiences much lower fraction of bank liquidation and default. Panels e and f show that the two bank networks perform similarly in terms of the cost measures due to liquidation and default.

The above results hold if we instead shock all the NYC banks by reducing the level of expected loan return rate $\bar{e}$. Overall, under low aggregate risk, for all sizes and types of shocks to NYC banks, the 1867 network is more robust to top-to-bottom crises.

High aggregate risk

In sharp contrast, we find that the 1867 network turns more vulnerable to top-to-bottom crises when the aggregate economy has high risk, that is, when it features either low expected return rate or high volatility. Consider a baseline return distribution $\bar{e} = 0$, $\sigma_e = 0.2$. With loan investment return volatility at 20%, the economy on average is experiencing a high level of risk. In such a situation, we simulate top-to-bottom crises by increasing the loan return volatility σ_e of all NYC banks by up to 0.5. NYC banks have higher return volatility and therefore higher chances of incurring liquidation cost and further default. Figure 6 shows the simulation results. As we can see in Figure 6, all the systemic risk measures appear higher in 1867 (the red dashed curves) than 1862 (the black solid curves). This shows that the post-Acts (1867) network has much higher chances of joint liquidation and default compared to that of year 1862.

In particular, the systemic risk measures show much higher magnitude in a high aggregate state when comparing Figure 6 with Figure 5. When all the NYC banks have return volatility 0.3, the systemic risk in terms of probability of a joint liquidation event in 1867 can be 0 or 90% depending on the aggregate state. The phase transition of financial stability demonstrated here confirms the "robust-yet-fragile" nature of the bank network, which also echoes the "the knife-edge dynamics" highlighted in Haldane (2013).[20] The above results are robust if we instead shock the NYC banks by reducing the level of expected loan return rate $\bar{e}$. Overall, for all sizes and types of shocks to all NYC banks, the 1867 network is more fragile to the top-to-bottom

[20]Note that the result is in contrast to Nier, Yang, Yorulmazer, and Alentorn (2007) who find that initial small increase in connectivity increases the contagion effect; but after a certain threshold value, connectivity improves the ability of a banking system to absorb shocks.

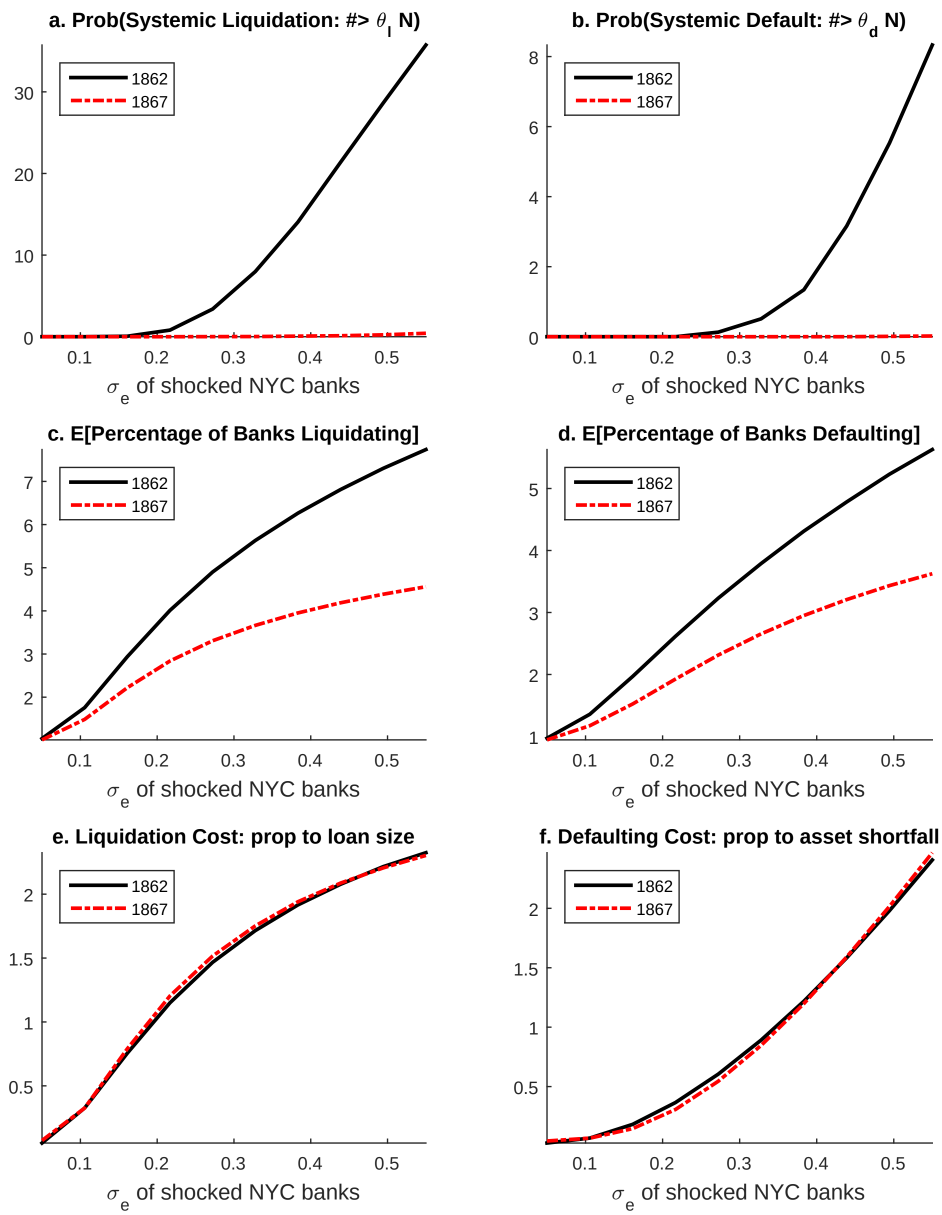


Figure 5. Top-to-Bottom Crises: in good times with low aggregate volatility This figure shows the changes in the financial stability measures when we increase the loan return volatility σ_e of NYC banks by up to 0.5 in good times when the aggregate condition features low volatility ($(\bar{e} = 0,\ \sigma_e = 0.05)$). The horizontal axis indicates the level of loan return volatility σ_e for all NYC banks. The vertical axis indicates, respectively in Panels a-f, the probability of systemic liquidation event, the probability of a systemic default event, the expected percentage of banks liquidating, the expected percentage of banks defaulting, the expected liquidation cost proportional to the bank loan size normalized by total value of the banking sector, and the expected defaulting cost proportional to asset shortfall normalized by total value of the banking sector. All Values are in percentages. All black solid curves plot the measures before the Acts (1862) and all red dashed curves stand for post-Acts (1867).

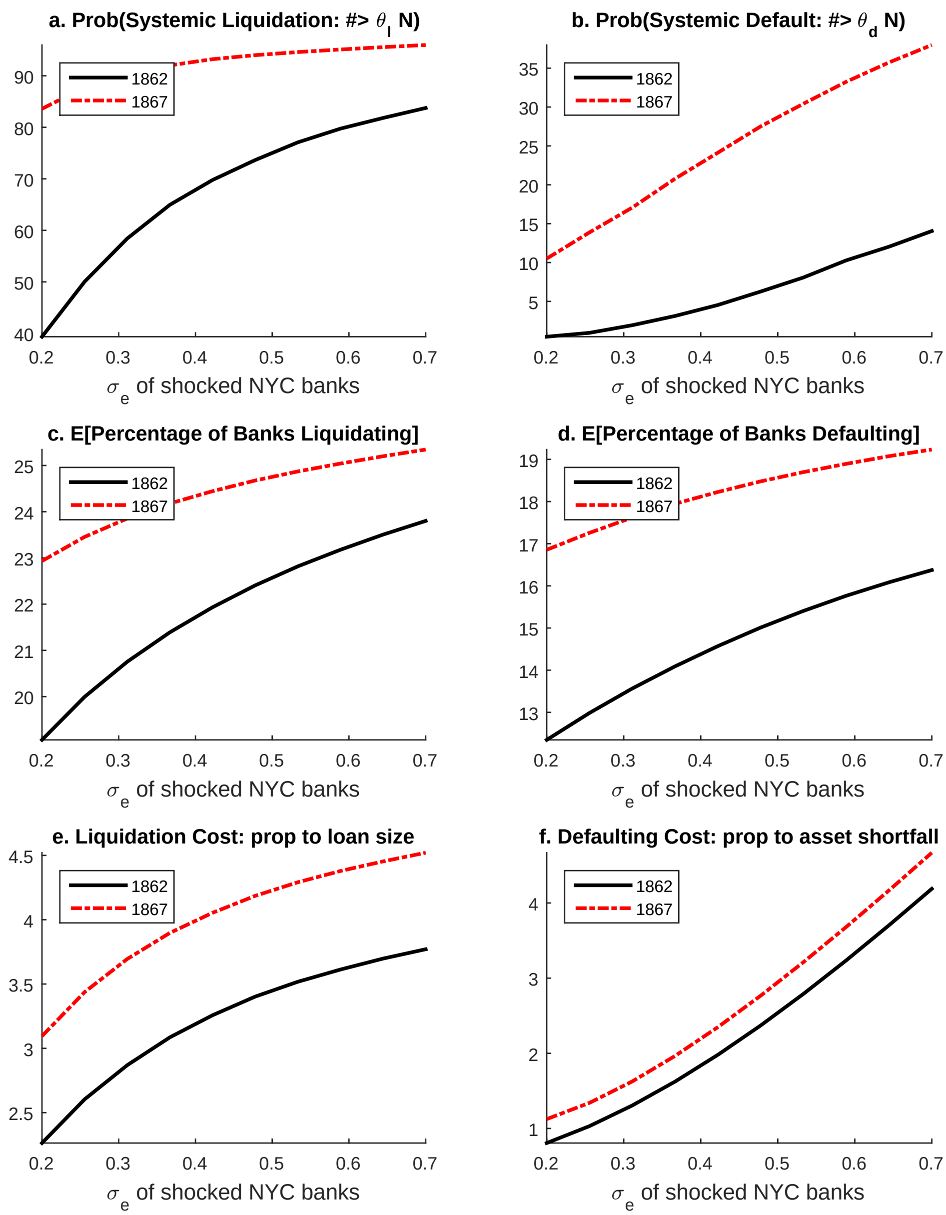


Figure 6. Top-to-Bottom Crises: in bad times with high aggregate volatility This figure shows the changes in the financial stability measures when we increase the loan return volatility σ_e of NYC banks by up to 0.5 in bad times when the aggregate condition features high volatility $((\bar{e} = 0,\ \sigma_e = 0.2))$. The horizontal axis indicates the level of loan return volatility σ_e for all NYC banks. The vertical axis indicates respectively from panel a-f, the probability of systemic liquidation event, the probability of a systemic default event, the expected percentage of banks liquidating, the expected percentage of banks defaulting, the expected liquidation cost proportional to the bank loan size normalized by total value of the banking sector, and the expected defaulting cost proportional to asset shortfall normalized by total value of the banking sector. All Values are in percentages. All black solid curves plot the measures before the Acts (1862), and all red dashed curves stand for post-Acts (1867).

crises under high aggregate risk.

5.4 Bottom-to-top Crises

As discussed in Section 2.3, bottom-to-top crises occurred when liquidity shocks originated from country banks and spread to reserve and central reserve cities. We simulate bottom-to-top crises by setting $W^D = 1$ for all country banks. Under such scenario, household depositors withdrawal early from country banks. We compute and compare the financial stability measures by plugging in the balance sheet data and the linkage matrix empirically observed in 1862 and 1867.

Results show that after the National Banking Acts the banking system became more fragile to shocks originating from the country banks regardless of the sizes or types of the shocks we feed in the simulation. For example, we start from a baseline distribution of $\bar{e} = 0$ and $\sigma_e = 0.1$. We shock all the country banks by increasing their loan return volatility by up to 0.5. As a result, all the country banks have higher chances of liquidation (although their return draws are independent from each other). Subsequently, a systemic withdrawal of reserves by the bottom tier, i.e. the country banks, occurs. This further triggers a liquidity shortage at the upper tier banks, and consequently, banks in reserve cities and New York cities have higher chances of liquidation. Along the bank networks, the liquidity shocks from the bottom peripheral banks become systemic.

Figure 7 show the results from simulation and indicate that the 1867 bank network is much more fragile to bottom-to-top crises. As the volatility of country bank loan returns increases, the 1867 network starts to show higher chances of systemic liquidation and default. Not only does the joint liquidation event becomes extremely likely (up to 90%), the percentage of banks experiencing liquidation and default also exceeds 25%. Even normalized by the total size of balance sheets of the year, the proportional liquidation and default costs in 1867 shoot up to around 2% of the entire dollar value of the banking sector.

The above results are without loss of generality and hold if we perform the simulation with different shock size, type, and under various aggregate economic conditions.

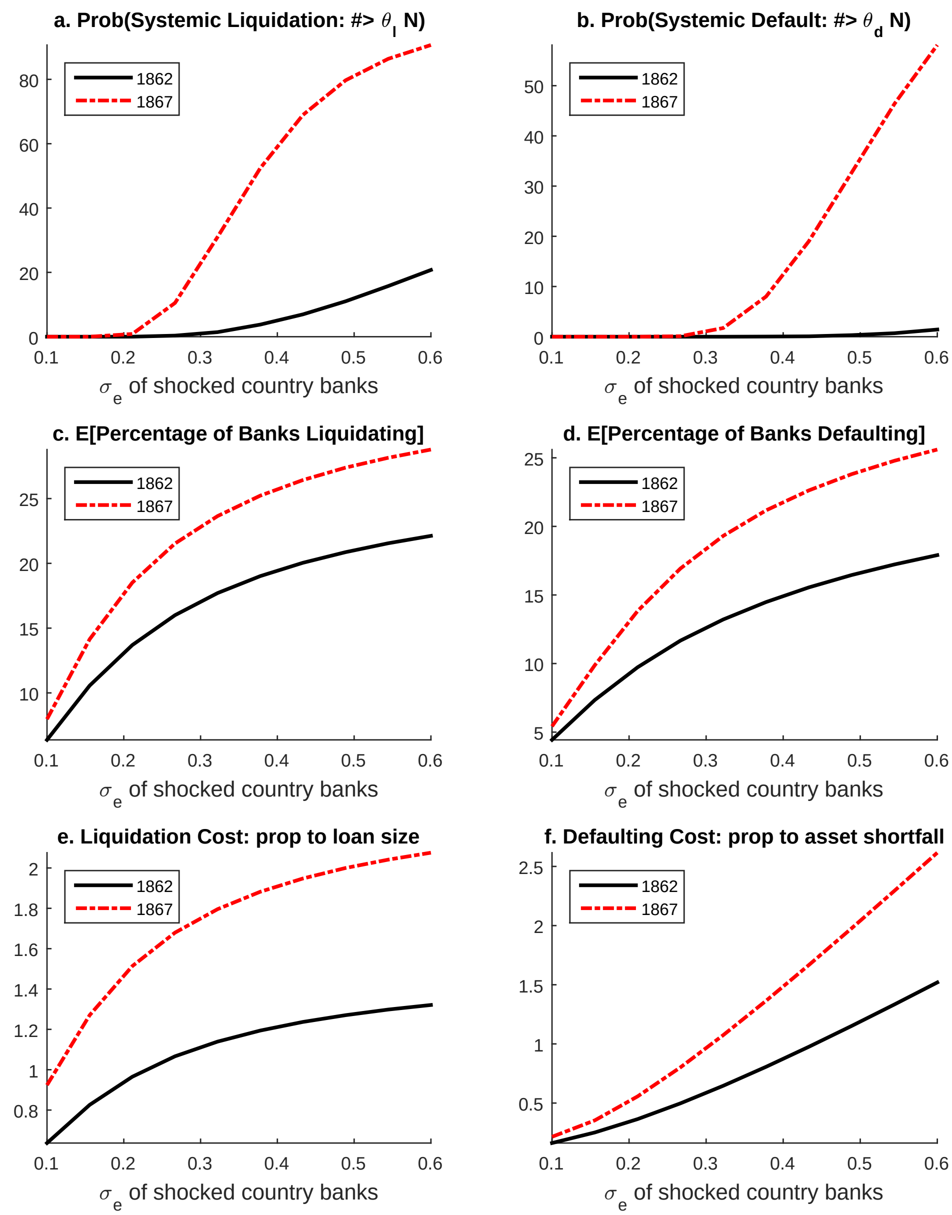


Figure 7. Bottom-to-Top Crises This figure shows the changes in the financial stability measures when we increase the loan return volatility σ_e of all country banks by up to 0.5 when all other banks' volatility remain at $\sigma_e = 0.1$. The horizontal axis indicates the level of loan return volatility σ_e for all country banks. The vertical axis indicates respectively from panel a-f, the probability of systemic liquidation event, the probability of a systemic default event, the expected percentage of banks liquidating, the expected percentage of banks defaulting, the expected liquidation cost proportional to the bank loan size normalized by total value of the banking sector, and the expected defaulting cost proportional to asset shortfall normalized by total value of the banking sector. All Values are in percentages. All black solid curves plot the measures before the Acts (1862), and all red dashed curves for post-Acts (1867).

Table 6. CONTAGION RISK OF LIQUIDATION AND DEFAULT UNDER VARIOUS SHOCKS

% of banks	Shocks to NYC banks				Shocks to country banks	
	in good times		in bad times			
Liquidation	$\Delta\sigma_{NYC} = 0.2$	$\Delta\sigma_{NYC} = 0.5$	$\Delta\sigma_{NYC} = 0.2$	$\Delta\sigma_{NYC} = 0.5$	$\Delta\sigma_c = 0.2$	$\Delta\sigma_c = 0.5$
1862	2.44	3.25	13.82	14.63	0.81	0.81
1867	0.49	0.99	16.83	16.83	1.98	1.98
Default						
1862	2.44	3.25	10.40	10.40	0	0
1867	0.49	0.49	12.19	13.01	0.99	0.99

Notes: This table shows the calculated contagion risks from simulation. The six columns show the percentage of bank liquidation and default that are caused indirectly by shocked banks, respectively NYC banks in low aggregate volatility state (good times), NYC banks in high aggregate volatility state (bad times), and shocks to country banks. In the low aggregate volatility state, all banks have loan return distribution $\bar{e} = 0$, $\sigma_e = 0.05$. In the high aggregate volatility state, all banks have loan return distribution $\bar{e} = 0$, $\sigma_e = 0.2$. We increase the volatility of NYC banks by $\Delta\sigma_{NYC} = 0.2$ and $\Delta\sigma_{NYC} = 0.5$ and compared the percentage of banks liquidating and defaulting indirectly before the Acts (1862) vs. post-Acts (1867). In the last exercise, when all banks draw from $\bar{e} = 0$, $\sigma_e = 0.1$, we increase the volatility of country banks by $\Delta\sigma_c = 0.2$ and $\Delta\sigma_c = 0.5$ and compared the percentage of banks liquidating and defaulting indirectly before the Acts (1862) vs. post-Acts (1867).

5.5 Contagion Risks

We look at contagion risks in the 1862 and 1867 bank networks across all three sets of simulations. We compute the expected number of banks liquidating and defaulting minus the number of banks directly shocked with either negative $\bar{e}$ or higher σ_e, as a percentage of total bank number. The results from contagion risks echo the findings with the other measures of systemic risk.

Table 6 shows the outcomes of top-to-bottom crises in both good and bad times, as well as bottom-to-top crises. In "good times," all banks have loan return distribution $\bar{e} = 0$, $\sigma_e = 0.05$. In "bad times," all banks have loan return distribution $\bar{e} = 0$, $\sigma_e = 0.2$. For both cases, we increase the volatility of NYC banks by $\Delta\sigma_{NYC} = 0.2$ and $\Delta\sigma_{NYC} = 0.5$ and compared the percentage of banks liquidating and defaulting indirectly before the Acts (1862) vs. post-Acts (1867). Results show that the 1867 bank network features much lower contagion risks when top-to-bottom crises occur in good times, but much higher contagion risks when top-to-bottom crises occur in bad times.

In the last exercise, when all banks draw from return distribution $\bar{e} = 0$, $\sigma_e = 0.1$, we increase the volatility of all country banks by $\Delta\sigma_c = 0.2$ and $\Delta\sigma_c = 0.5$. Results show that the magnitude of contagion is lower in general for bottom-to-top crises and that when bottom-to-top crises hit, the 1867 bank network always shows higher contagion risk.

5.6 Comparing top-to-bottom and bottom-to-top crises

Both top-to-bottom and bottom-to-top crises occurred in the post-Acts era; however, it is unclear which type of crises was more severe in generating higher systemic risk. Comparing the bank networks in 1862 and 1867, not only the structure of the networks evolved dramatically, the population and balance sheets of different tiers of banks changed as well. First, the number of country banks to NYC banks grew during this period. For 1862, there were 22 NYC banks, 64 country banks, and 37 banks in other reserve cities; whereas by 1867, there were only 19 NYC banks, but 132 country banks, and 51 in other reserve cities. Second, NYC banks which were already relatively larger in terms of asset size to country banks experienced expanding balance sheets. In 1862, an average NYC bank had a total asset value \$6.2M, 10 times that of the average country bank; whereas in 1867, an average NYC bank had total asset value \$12.9M, 25 times that of the average country bank. All these highlighted changes render the comparison between the top-to-bottom and bottom-to-top crises challenging.

To give more comparable results, we perform the following exercise. For each year, we respectively shock a random fraction of NYC banks and country banks by increasing the loan return volatility. We compute the level of expected percentage of bank defaults generated by shocking a given fraction of randomly drawn NYC banks. Further, we solve for the required fraction of country banks shocked such that the same level of expected percentage of bank defaults can be generated. Figure 8 panel a plots the pairs of fractions NYC and country banks shocked in a scatter plot. Black curves are for pre-Acts(1862) and red curves are for post-Acts (1867). Relative to 1862, a smaller fraction of country banks (or larger number of NYC banks) must suffer a shock to generate the same level of defaults percentage.

Similarly we apply the method to compute the percentage of bank default costs (normalized by the total value of bank balance sheets of the year). Figure 8 panel b plots the results. Relative to 1862, a smaller fraction of country banks shocked (or larger number of NYC banks) is required to generate the same level of default costs. Both of these plots suggest that the impact of the

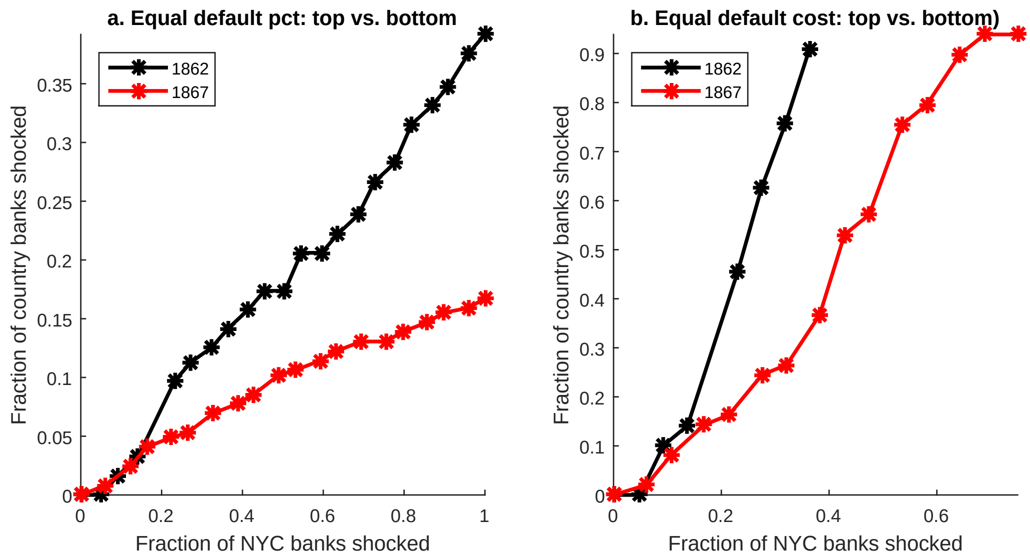


Figure 8. Comparing top-to-bottom and bottom-to-top crises This figure shows the relative severeness of top-to-bottom crises and bottom-to-top crises in 1862 and 1867. In Panel a, for each point in the scatter plots, the same level of expected percentage of bank defaults can be generated by shocking a randomly drawn fraction of NYC banks (horizontal axis), or equivalently by shocking a randomly drawn fraction of country banks (vertical axis). In Panel b, for each point in the scatter plots, the same level of bank default costs (normalized by the total value of bank balance sheets of the year) can be generated by shocking a randomly drawn fraction of NYC banks (horizontal axis), or equivalently by shocking a randomly drawn fraction of country banks (vertical axis). The benchmark is $\bar{e} = 0$, $\sigma_e = 0.1$ and we increase the volatility of all randomly shocked banks by $\Delta\sigma = 0.5$. Black curves are for pre-Acts(1862) and red curves are for post-Acts (1867).

network increased the impact of a bottom-to-top crisis while decreasing that of a top-to-bottom crisis. Note that the above results for both plots only matter when the fraction in concern is large enough - when only a minimal number of banks are affected, the curves in 1862 and 1867 nearly coincide.

To summarize this section of quantitative analysis, we feed *shocks of different origin, types, and sizes under various aggregate conditions* to the empirically observed bank reserve networks in 1862 and 1867. We show that post-Acts network improves financial stability only for top-to-bottom crises when the aggregate economy features low risk. However, in doing so it increased the vulnerability of the system for top-to-bottom crises when the aggregate economy has high risk, and for bottom-to-top crises in general. Overall the impact of National Banking Acts on systemic risk favored decreasing the systemic nature of top-to-bottom crisis while increasing bottom-to-top crisis.

6 Conclusion

The global financial crisis of 2007 - 2008 has shown how interconnectedness among financial institutions can amplify liquidity shocks and contribute to financial fragility. In response, policymakers and academics alike are attempting to understand how financial networks can turn liquidity crises systemic. While many theoretical models have been introduced, not much empirical work has been done due to the lack of data on interconnectedness formed by various financial contracts.

We overcome the limitations by examining a novel historical experiment, the passage of the National Banking Acts of 1863-1864. By establishing reserve requirements that dictated the amounts and location of interbank deposits, the Acts reshaped the structure of bank networks into a 3-tiered pyramid with more concentration and shorter chains. The contribution of this paper is to use the empirically observed bank reserve linkages and quantitatively examine the structure of bank networks and its impact on the banking system before and after the Acts. We find that the bank networks became "*robust-yet-fragile*" after the Acts, consistent with theoretical evaluations of centralized financial networks. In particular, we find that in normal times the post-Acts bank network is more robust to top-to-bottom crises with liquidity shocks originating from banks in New York City. However, it is more fragile to the top-to-bottom crises when the aggregate economy experiences low returns or high uncertainty. Additionally, we find the network is more vulnerable to liquidity shocks driven by the withdrawal of deposits by banks outside of financial centers.

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Appendix I: Sample Data

Due to the York County Bank, from the following named solvent banks, respectively, on the 1st day of November, 1864:

Bank of Chambersburg	$1,306 03
Bank of Gettysburg	3,136 53
Bank of Commerce, New York	687 98
Bank of Northern Liberties	622 14
Carlisle Deposit Bank	2,067 94
Exchange Bank, Pittsburg	637 09
Franklin Bank, Baltimore	6,725 03
Girard Bank	680 17
Hanover Savings Fund Society	667 19
Jay Cooke & Co	1,860 60
Lancaster County Bank	72 94
Mechanics' Bank, Harrisburg	2,242 00
Shrewsbury Savings Institution	253 24
Western Bank, Philadelphia	4,320 18
Western Bank, Baltimore	4,695 69
York Bank	6,913 85
	36,888 60

Figure 9. Pennslyania State Bank Report: York County Bank This table contains all the corresponding banks that the bank had deposits with.

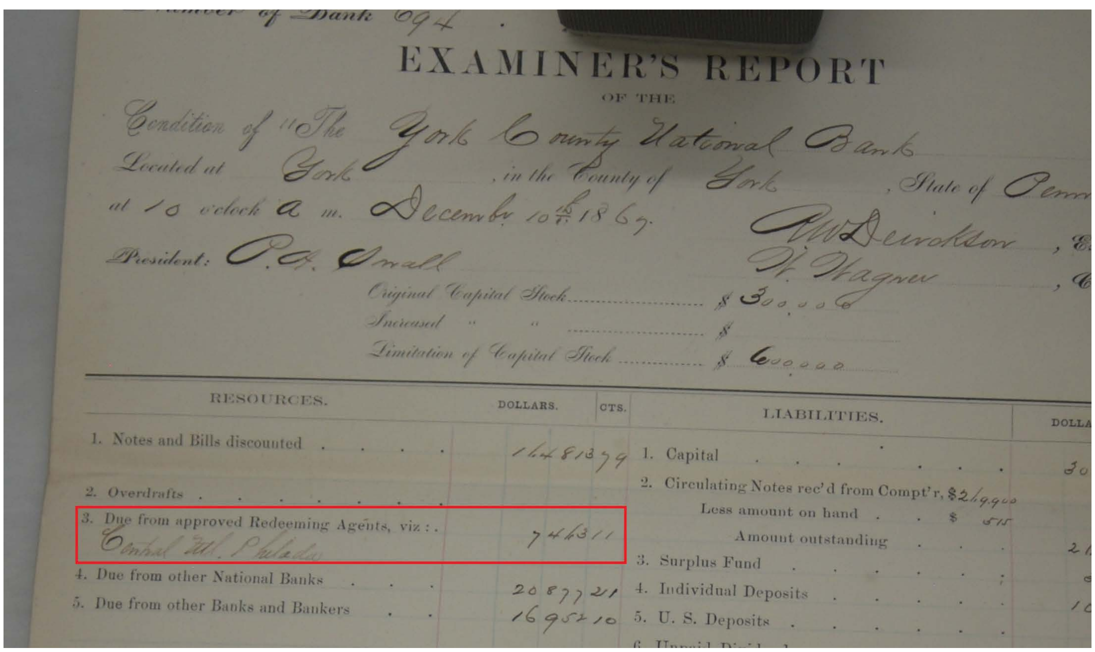


Figure 10. OCC Bank Examiners Report: York County National Bank This figure shows the hand written examiners report that was filled annually. The major correspondent banks that the bank had deposits is highlighted in the red box.

Appendix II: Bank Networks on the Map

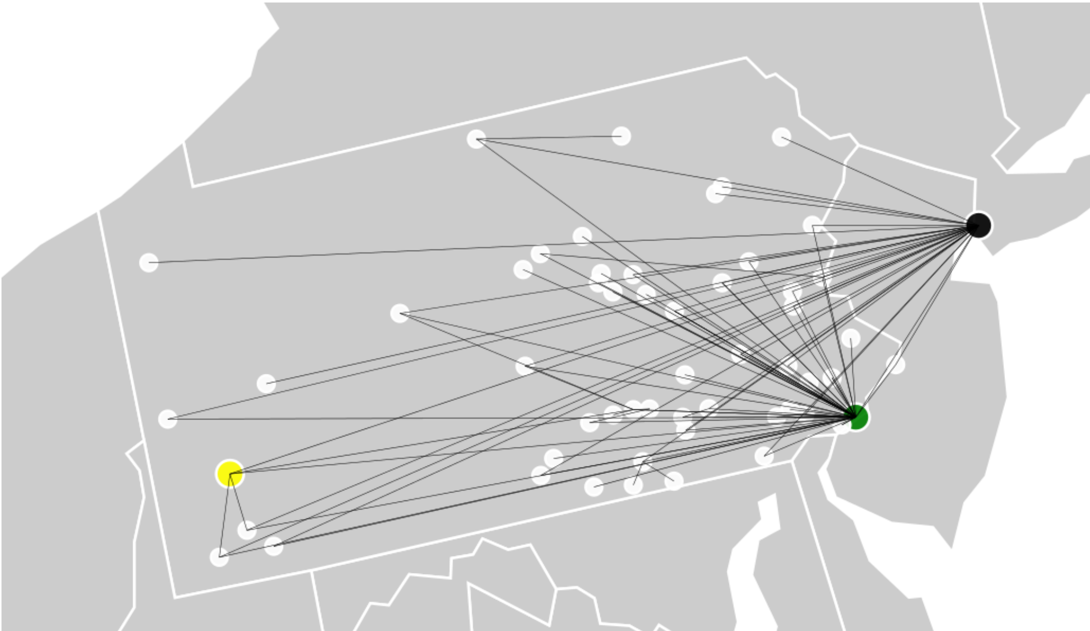


Figure 11. 1862 Bank Networks on the Map This figure shows

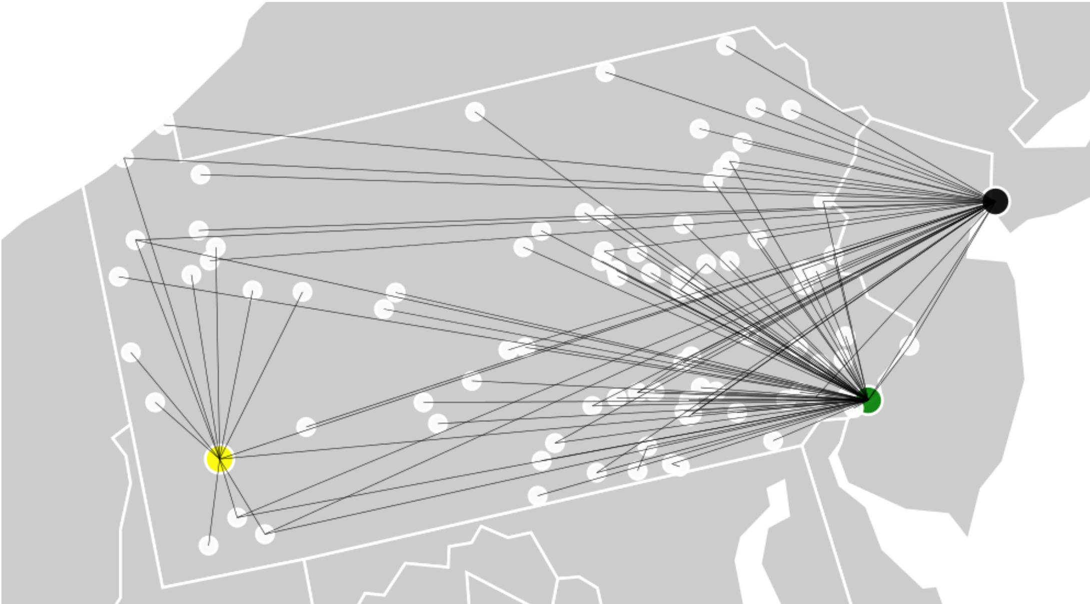
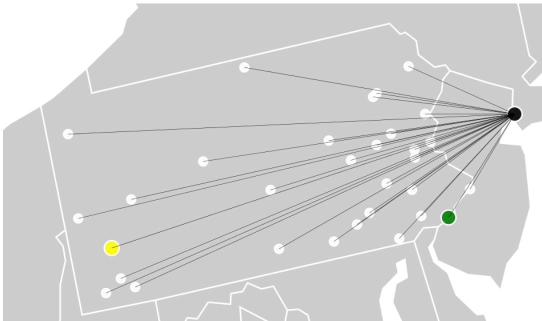
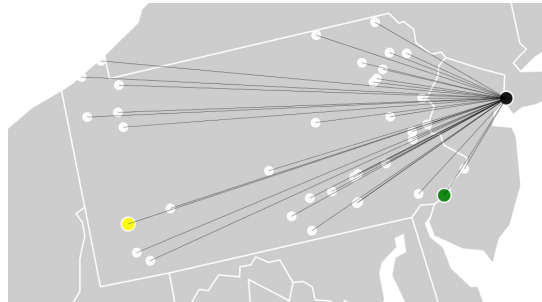


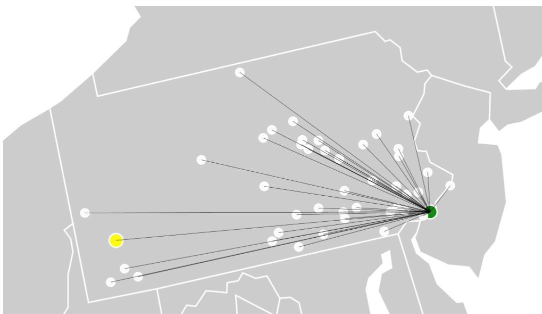
Figure 12. 1867 Bank Networks on the Map This figure shows



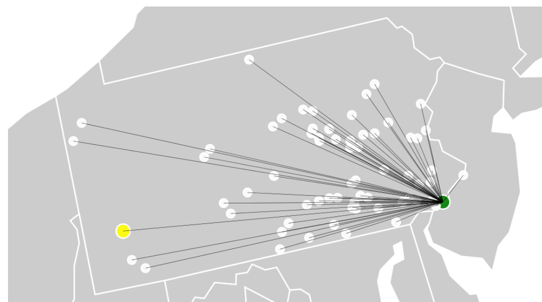
(a) 1862NYC



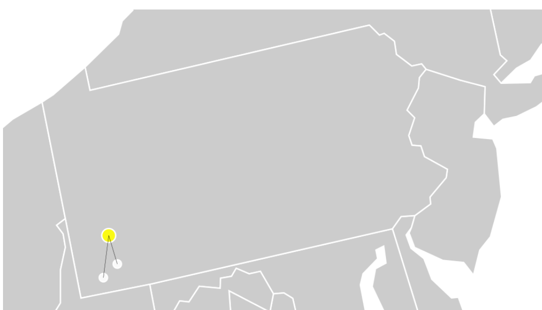
(b) 1867NYC



(c) 1862PHI

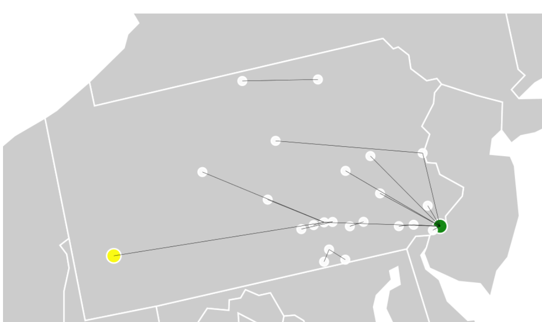


(d) 1867PHI

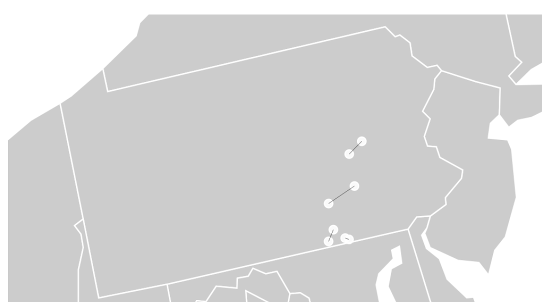


(e) 1862PITT

(f) 1867PITT



(g) 1862Other



(h) 1867Other

Figure 13. Compare Bank Networks by Location