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

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Abstract

The reserve requirements established by the National Banking Acts (NBA) dictated the amounts and location of interbank deposits, thereby reshaping the structure of bank networks. Using unique data on bank balance sheets along with detailed interbank deposits in 1862 and 1867 in Pennsylvania, we study how the NBA changed the bank network structure and further quantify the effect on financial stability in a model of interbank networks with liquidity withdrawal. We find that the NBA led to a concentration of bank linkages both at the city and bank level, creating systemically important banks in major financial centers. Our quantitative results show that the newly emerged system was "robust-yet-fragile": while a concentration of linkages made the system more resilient in general, it increased the likelihood of contagion when financial center banks faced large shocks.

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1 Introduction

The recent financial crisis has shown how the interconnectedness among financial institutions can pose systemic risk to the financial system. When a highly interconnected institution, such as was the case with Lehman Brothers, becomes distressed, their counterparties may also experience losses and limited access to liquidity. As such, an idiosyncratic shock to one institution can turn into a system-wide shock. In response, economists and policymakers have initiated great efforts to assess the relationship between network structure and systemic risk. While many theoretical models have been introduced (e.g. Allen and Gale (2000), Elliott, Golub, and Jackson (2014), Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015)), existing empirical work has been limited by several important challenges.

One notable challenge originates from the lack of detailed comprehensive data on the structure of financial networks. First, with limited information on the topology of financial networks, it is difficult to assess systemic susceptibility to contagion. Second, it is difficult to disentangle counterparty exposures arising from various instruments.

In this paper, we examine how the National Banking Acts (NBA) of 1863 and 1864 changed the structure of bank networks and affected the stability of the banking system. The NBA established a reserve hierarchy that consolidated New York City's position as the nation's money center. Specifically, we analyze the impact of the NBA on the topology of interbank networks and how it affected banks' liquidity management. Then, we build a model and quantitatively examine how the changes in interbank network structure affect the transmission of liquidity shocks in the banking system.

The banking system around the passage of the NBA provides us a unique setting to examine how systemic risk arises from bank networks. First, we overcome data challenges by constructing a dataset on banks in Pennsylvania (and New York City) that are listed in the annual report of state banks and examination reports of national banks for years 1862 and 1867. The data provides information on individual correspondent relationships, allowing us to have a complete picture of the topology of the bank networks during that period. The state banking reports provide detailed information on "due from other banks" by individual debtor bank on the asset side of the balance sheets. Similarly, the examination reports list the legal correspondents with whom the national banks placed funds and the amounts they held with each individual correspondent on the day of the examination. Such detailed information on bank balance sheets is significant as it allows us to identify the topology of the interbank networks and provides us a measure of the intensity of these relationships.[1]

Second, the unique structure of the U.S. banking industry during this period helps us overcome the difficulty in identifying risk channels. While financial institutions today have various types of counterparty exposures due to various financial instruments held by a number of parties, banks at the time faced counterparty exposures solely due to interbank relationships. Moreover, the legislation offers us an opportunity to observe the structural evolution of the interbank network. This allows us to compare different network structures and analyze the relationship between network structures and financial stability.

We document two key features of the interbank network before the NBA. First, the interbank network already exhibited a core-periphery structure as rural banks dealt exclusively with banks in financial centers. In particular, many banks placed deposits in New York and Philadelphia. However, they also used banks in other regional financial centers such as Harrisburg and Scranton. Second, the size of correspondent markets in New York City and that in Philadelphia was comparable, indicating that Philadelphia was an important financial center that may have served as the ultimate repository destination of interbank deposits much like New York City.

As the NBA allowed banks to use interbank deposits to meet legal reserve requirements, the reserve pyramid with three distinct tiers emerged. Interbank deposits became heavily concentrated in cities that were designated as reserve and central reserve cities. In particular, Pittsburgh emerged as a new financial center as it was designated as a reserve city. At the same time, other regional centers experienced a reduction in the interbank deposits held by rural banks. In addition, from looking at the deposits due to banks, we find that New York City became the ultimate destination of interbank deposits. The size of correspondent deposits in New York City became much larger than that of Philadelphia. Lastly, banks in financial centers increased their cash holdings in order to create larger liquidity buffers in case of deposit withdrawals.

[1] We use the term "correspondents" to indicate the banks in which other banks place interbank deposits. We use the terms "correspondent networks" and "interbank networks" interchangeably throughout the paper.

To summarize, we find that the NBA increased the Pennsylvanian banks' vulnerability to financial difficulties in New York City. This is because Pennsylvanian banks became more connected to New York City banks, which held dominant position in the financial system. In addition, the increased connectivity of rural banks in other part of the country to New York City increased the Pennsylvanian banks' vulnerabilities to liquidity shortages of these banks as well since these banks withdrew from New York City correspondents in the time of monetary stringency.

To examine quantitatively how such changes in bank network structures affect financial stability, we build a model of interbank networks featuring liquidity withdrawals by extending Eisenberg and Noe (2001) interbank payment system. In our twp period model, banks may experience runs, asset liquidation, and default due to a maturity mismatch between short term liquid liabilities (demand deposits and interbank deposits) and long term illiquid asset investments. Such a framework allows us to study the impact of banking panics due to deposit withdrawals, both by local and institutional depositors.

We then use the model to simulate two types of banking crises and compare systemic risk measures for the years before and after the NBA. Four of the major banking crises started from investment loss in New York City and spread to other parts of the system. To simulate such crises, we reduce expected investment returns of New York City banks. The second type of crises occurred when banks outside of the financial center had liquidity shortages due to agricultural cycles. Banks outside the city withdrew deposits from their city correspondents, who then experienced liquidity shortages and liquidated their loans. For each simulated scenario, we measure the probability of joint liquidations among banks and compare the resilience of the banking system before and after the NBA.

We find that the NBA induced a "*robust-yet-fragile*" nature of the more concentrated financial networks. The banking system becomes more robust as long as the most connected institutions avoid large liquidity shocks. However, when the losses are large enough to trigger liquidation and default at these systemically important banks where interbank depositors are concentrated, linkages start serving as channels for contagion. Financial center banks fail to repay deposits in full to their respondents, thereby causing runs and systemic liquidation. On the other hand, the post-NBA interbank network is more resilient to liquidity shocks that originate from the deposit withdrawals by banks outside financial centers. Even if interbank linkage can pass on contagious withdrawals upwards along the pyramid, the financial center banks tend to hold enough liquid assets to meet such demand.

Our results show that financial stability depends crucially on the concentration of network linkages, the composition of bank balance sheets, and the magnitude of shocks. In particular, the concentration of linkages in New York City banks made the banking system becomes more robust to mild shocks. This is because the concentration facilitates risk diversification. Since each financial center bank has a large number of depositors, only a small fraction of loss at financial center banks is passed on to each individual depositors. At the same time, such a system is more fragile when the highly connected financial center banks face large shocks. Large losses at the most connected institutions enable the transmission of liquidity shocks to a large number of counterparties simultaneously, increasing the likelihood of systemic liquidation events. In this case, concentrated linkages act as a mechanism for contagion. This "*robust-yet-fragile*" nature of the interbank network after the NBA is consistent with the "knife-edge flipping" concept in Haldane (2013) and the theoretical findings in Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) and Gai and Kapadia (2010).

We contribute to the theoretical financial networks literature arguing that certain network structures lead to contagion and systemic risk (Allen and Gale (2000), Eisenberg and Noe (2001)).[2] In particular, Eisenberg and Noe (2001) develop a framework in which firms have interconnected liability relationships. This clearing equilibrium can be applied to assess contagious default. We contribute by adding contagious withdrawals and liquidation to the Eisenberg and Noe (2001) payment framework. Such new features allow us to study not only default cascades triggered by asset losses, but also the propagation of funding risk due to contagious deposit withdrawals.

Our paper also adds to the empirical and quantitative studies on financial network and stability (e.g. Furfine (2003), Nier, Yang, Yorulmazer, and Alentorn (2007), Gai and Kapadia (2010), and Glasserman and Young (2015).) However, due to difficulties in identifying exact linkages and risk exposures among institutions, most studies are based on simulations rather

[2] An incomplete list includes Dasgupta (2004), 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), Greenwood, Landier, and Thesmar (2015), and Wang (2015).

than using empirical networks. Few exceptions include Gofman (2014), who studies the effect of restricting bank interconnectedness by estimating an interbank lending model to match statistics on the Fed funds market. Also, Stanton, Walden, and Wallace (2014) use mortgage-origination and securitization network data to estimate a model of network formation. Nonetheless, the arguments are limited to the extent that exact bilateral risk exposures are not observable in the modern banking system. Our paper fills this gap by using empirically observed interbank deposit relationships as well as bank balance sheets to construct bank networks.

Lastly, our paper contributes to the literature on financial panics during the National Banking era by empirically examining how the "pyramiding" of bank reserves contributed to systemic liquidity crises. While several studies have discussed how the structure of the interbank network was a major source of systemic risk during this period, they did not provide empirical evidence or quantitative analysis on how it turned liquidity crises systemic.[3] Moreover, none of these studies compare the structure of the interbank network before and after the NBA and assess how differences in interbank networks affected financial panics. We contribute to this literature by providing empirical evidence using a micro-level data.

Our paper proceeds as follows. Section 2 presents historical background on the National Banking Acts and the correspondent banking system. Section 3 provides data and summary statistics. Section 4 describes the model set up, and Section 5 analyzes the quantitative results. A final section 6 concludes.

2 Historical Background

The provisions of the National Banking Acts (NBA) represented a major event in the development of the banking and financial infrastructure of the United States. The NBA was passed during the US Civil War in order to create a demand for U.S. Treasury bonds. The NBA created a system of national banks, and encouraged state banks to convert. This new class of banks were allowed to issue bank notes up to 90% of the lower of par or market value of the U.S. Treasury securities they held. Because national bank notes were collateralized by U.S. treasuries and traded at par, a uniform national currency was created . Prior to the NBA, banks issued

[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), Calomiris and Carlson (2016) and Wicker (2000).

individual private bank notes that traded at discounts to face value when traded at a distance from the issuing bank, making transacting difficult (Gorton and Muir (2016)). In addition, the NBA established a set of capital and reserve regulations. In this section, we examine the U.S. banking system during the National Banking Era: (1) the reserve hierarchy under the NBA, which was characterized by the concentration of interbank deposits in reserve and central reserve cities and (2) the banking panics of the National Banking Era.

2.1 Reserve Hierarchy under the National Banking Acts

Interbank networks developed in the early 1800s when advances in transportation and communication technologies led to rapid growth in interregional trade and increased need for interregional capital transfer within the United States. However, banks could not accommodate interregional payments easily because most banks operated as unit banks under legal restrictions on branching. Interbank network relationships were an institutional response to circumvent branching restrictions. Small rural banks maintained deposits on reserve with larger city banks which in turn cleared their checks through big city clearinghouses. We refer to banks placing deposits in other banks as *respondents* and banks providing the services as *correspondents*. In particular, New York City had emerged as the preeminent correspondent banking center by the 1850s.[4]

One of the most important regulations under the NBA, and the focal event of this paper, was the creation of a reserve hierarchy, as shown in Table 1. The top tier consisted of central reserve city banks. They were required to hold a 25% lawful currency on deposits and notes.[5] Central reserve city banks had to keep all their reserves in their vault. The second tier of banks, the reserve city banks, were required to hold a 25% reserve.[6] 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 lawful currency. Lastly, the bottom tier was composed of country banks. They were required to hold a 15% reserve on deposits, three-fifths of the 15% as deposits with a correspondent bank in a

[4] The correspondent banking offered other valuable services as well. Correspondent deposits placed in city correspondents provided rural banks an opportunity to invest in liquid assets that paid interest instead of using for them for lending to accommodate local lending, thereby allowing them to diversity their asset portfolios. Also, these balances in major cities, especially New York, were traded among local banks outside financial centers. This helped them to adjust the level of their correspondent accounts at lower transactions costs.

[5] 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.

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

Table 1. National Bank Reserve Requirements

Tier	Banks	Location	Reserve ratio	Max reserve deposit	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 or central reserve city with the rest in their vault.[7]

This tiered system is often said to have created a concentration of correspondent balances in New York City and 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).

2.2 Banking Panics of the National Banking Era

Under the National Banking System, the United states experienced a series of serious banking panics. These panics occurred because holders of bank liabilities demanded the conversion of their debt claims into cash en masse, so the banks acted collectively to avoid suspension by issuing clearinghouse loan certificates (Calomiris and Gorton (1991)).[8] The pyramiding of reserves contributed to magnifying the extent of banking crises during the period of stress.

As shown in the National Monetary Commission reports, contemporary policymakers, bankers, and economists considered the "pyramiding of reserves" and the interbank systems' inability to accommodate seasonal flows of funds between New York and the interior to be sources of systemic risk. In this view, banking 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", causing a

[7]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.

[8]There were five major financial panics during the National Banking Era (Sprague (1910)). 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 (Calomiris and Gorton (1991))

drain on the reserves of central reserve city.[9] The withdrawal of funds by country banks resulted in financial strains on city correspondents, prompting a liquidity crisis of city banks and a suspension of cash payments in major cities.

In addition, unexpected financial shocks in New York City were also an important source of systemic liquidity crises. New York City banks were "systemically important" for their size and interconnectedness. 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 due to an initial financial shock 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 banking 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)). One possibility is 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 examine how the banking system responded to these two types of liquidity shocks before and after the NBA and discuss the implication for the stability of the system as a whole.

[9] Bank panics 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.

3 Data and Summary Statistics

We use a combination of data sources to study how the introduction of the NBA changed the structure of bank networks and affected the stability of the banking system. 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.

From these reports, we collected information on balance sheets and correspondent relationships for state and national banks. For state banks, we have information on the amount that was due from each debtor bank and the name of each of these banks. For national banks, we collected information on the amount that was due from each agent and the name of each of those agents. While state banking reports provided complete information on correspondents, examination reports only recorded relationships between national banks and their approved reserve agents were recorded to verify whether national banks were holding these amounts at correspondent banks to meet required reserve requirements.[10]

For state banks, annual reports provided balance sheets at the quarterly frequency and the amounts due to each state-chartered Pennsylvania bank by individual debtor at the annual frequency. Balance sheet information is available for March, June, September, and November, while correspondence information is available for November of each year. We collect information on balance sheets and amounts due to each state-chartered Pennsylvania bank by individual debtor for November.

For national banks, not all correspondent banks were reported because the primary purpose of examinations was to verify whether national banks met legal reserve requirements. Country banks selected the national banks in reserve cities with which they wish to keep a portion of their legal reserve, and sent the names of the banks to the comptroller. Once approved, they were

[10] A "due-to" account is an liability on a bank's balance sheet that indicates the amount of deposits payable to another bank. In contrast a "due-from" account is an asset on a bank's balance sheet that indicates the amount of deposits currently held at another bank.

known as *approved reserve agents*. Similarly, national banks in reserve cities selected national banks in central reserve cities. Hence, for both country banks and reserve city banks, only amounts due from approved reserve agents in reserve cities and the central reserve city were enumerated. This means that amounts due from other banks in reserve cities and the central reserve city were not required to be reported. In addition, amounts due from other county banks did not need to be reported. For subject banks in the central reserve city, no due from information was required to be reported since these banks had to hold all their reserves in cash.

In order to document different types of due from relationships, examiners' reports report three types of due froms: "due from approved redeeming agents," "due from other national banks," and "due from other banks." For due from approved redeeming agents, each name of the agents is recorded with the corresponding amount. For due from other national banks and due from other banks, only aggregate amounts are reported.

The structure of these listings has important implications for how we analyze the data. During this period, most national banks had one reserve agent to keep their legal reserves. These reserve agents tended to be the major holder of national banks' correspondent deposits. On average, national banks kept 50 percent of total interbank deposits in one bank.[11] However, a few Philadelphia banks kept their reserves in multiple banks in New York City with about 20 percent of total interbank deposits in each bank. In order to make the data on state banks' correspondents comparable to that of national banks with their approved reserve agents, we only keep correspondents banks that held more than 20 percent of total interbank deposits.

We choose the years 1862 and 1867 because we wanted to capture the structure of bank networks before and after the enactment of the NBA. The data for 1862 only contains state banks and captures bank behavior before the unanticipated passage of the NBA. In contrast, the data for 1867 contains both state and national banks and captures bank behavior after the passage of the NBA. 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

[11] Calomiris and Carlson (2016) study the interbank network from the panic of 1893, where we they find similar values of 56 percent.

relationship, but still create a sample that includes national banks that used to be state banks in 1862. In addition, national examiners reports do not provide information on national banks reserve agents until 1867.[12]

In addition, we divide the sample of banks into four classes of banks - New York, Philadelphia, Pittsburgh, and country banks. We divide banks this way for three reasons. First, as documented in Weber (2003), differences in the needs of the customers of each of these classes of banks largely originated from location and contributed to how they interacted with each other. Second, the NBA designated New York as the central reserve city and Philadelphia and Pittsburgh as reserve cities. Banks faced faced different regulations based on location, and balance sheets reflected these differences. Specifically, New York banks were large and served as depositories of country banks. Country banks were generally small and served as creditors to banks in major financial centers. Both Philadelphia and Pittsburgh banks served as intermediaries for other banks by taking deposits from country banks and placing them in New York City banks. However, some Philadelphia banks behaved more like central reserve city banks by having large cash reserves and serving as ultimate depository institutions. In contrast, Pittsburgh banks behaved more like country banks by acting as creditor banks to financial center banks.

3.1 Balance Sheet Information

Table 2 shows the composition of balance sheets for New York, Philadelphia, Pittsburgh, and country banks in 1862 and 1867. Banks had a liquid balance sheet structure. Before the NBA, banks held 13 percent of cash, 20 percent of liquid securities, and 13 percent of interbank deposits (not reported in the table). After the NBA, banks held 12 percent of cash, 6 percent of liquid securities, and 8 percent of interbank deposits (not reported in the table). The amount of liquid assets other than cash decreased initially due to the reduction in the amount of liquid securities. This is because the NBA required banks to back their privately produced money in the form of bank-specific national bank notes with US Treasury bonds. In turn, these bonds were no longer considered liquid.

[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 U.S. Treasurers 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.

In addition, Table 2 reveals that banks that served as depositories for country banks increased their cash holdings after the NBA. New York banks increased their cash holdings significantly from 19 percent in 1862 to 38 percent in 1867. While higher cash holdings were required under the newly established reserve requirements, these banks were holding more than the amount required to meet these requirements. Banks in Philadelphia, which also served as bankers' banks at the time, also increased cash holdings. In contrast, Pittsburgh banks, which were not as important financial center banks as those in Philadelphia at the time, actually decreased cash holdings. The level of their cash holdings was close to that of country banks.

Table 2. Balance Sheet Summary Statistics

	New York City			*Philadelphia*			*Pittsburgh*			*Country Banks*		
Year = 1862	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets												
Cash	22	0.19	0.09	20	0.21	0.10	7	0.18	0.06	63	0.12	0.07
Liquid Securities	22	0.16	0.14	20	0.30	0.14	7	0.32	0.13	63	0.18	0.14
Due from other banks	22	0.04	0.02	20	0.03	0.04	7	0.12	0.04	63	0.18	0.10
Loans	22	0.58	0.17	20	0.40	0.12	7	0.36	0.12	63	0.49	0.12
Against Total Liabilities												
Equity	22	0.35	0.07	20	0.24	0.06	7	0.36	0.07	63	0.28	0.09
Bank notes	22	0.04	0.03	20	0.13	0.10	7	0.39	0.17	63	0.40	0.21
Deposits	22	0.43	0.13	20	0.51	0.09	7	0.23	0.12	63	0.27	0.20
Due to other banks	22	0.13	0.10	20	0.09	0.09	7	0.01	0.01	63	0.01	0.02
Year = 1867	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets												
Cash	19	0.38	0.15	24	0.31	0.08	15	0.12	0.07	132	0.14	0.06
Liquid Securities	19	0.06	0.10	24	0.08	0.10	15	0.08	0.14	132	0.09	0.12
Due from other banks	19	0.04	0.04	24	0.07	0.05	15	0.09	0.05	132	0.15	0.09
Loans	19	0.39	0.13	24	0.50	0.08	15	0.66	0.09	132	0.58	0.14
Against Total Liabilities												
Equity	19	0.25	0.11	24	0.30	0.08	15	0.42	0.14	132	0.38	0.10
Bank notes	19	0.09	0.05	24	0.15	0.07	15	0.21	0.12	132	0.26	0.10
Deposits	19	0.46	0.17	24	0.48	0.12	15	0.35	0.21	132	0.34	0.16
Due to other banks	19	0.19	0.17	24	0.06	0.08	15	0.02	0.03	132	0.03	0.03

Note: This table is based on authors' calculations. Equity = Capital + surplus and profits.
Source: Authors' calculations using data from *Several Banks and Savings Institutions of Pennsylvania* and *OCC National Bank Examination Reports*

The reserve requirement of the National Banking Act shifted the destination of interbank deposits. Table 3 provides information regarding the distribution of correspondent deposits for years 1862 and 1867. According to Table 3, newly established reserve requirements had a differential impact on banks, depending on location. Country banks reduced their balances

Table 3. Distribution of Interbank Deposits

	Philadelphia			*Pittsburgh*			*Country Banks*		
Year = 1862	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Over All Interbank Deposits									
New York City	11	0.48	0.21	7	0.66	0.14	24	**0.56**	0.25
Philadelphia	3	0.32	0.15	4	0.31	0.03	46	**0.61**	0.23
Pittsburgh	0	-	-	0	-	-	**0**	**-**	-
Other PA	0	-	-	1	0.28	-	6	0.53	0.30
Other U.S.	4	0.43	0.25	0	-	-	5	0.38	0.17
Year = 1867	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Over All Interbank Deposits									
New York City	24	0.29	0.29	13	0.67	0.26	51	**0.42**	0.32
Philadelphia	0	-	-	4	0.44	0.34	84	**0.45**	0.34
Pittsburgh	0	-	-	1	1.00	-	**16**	**0.48**	0.34
Other PA	0	-	-	0	-	-	8	0.31	0.30
Other U.S.	0	-	-	1	0.00	-	9	0.27	0.36

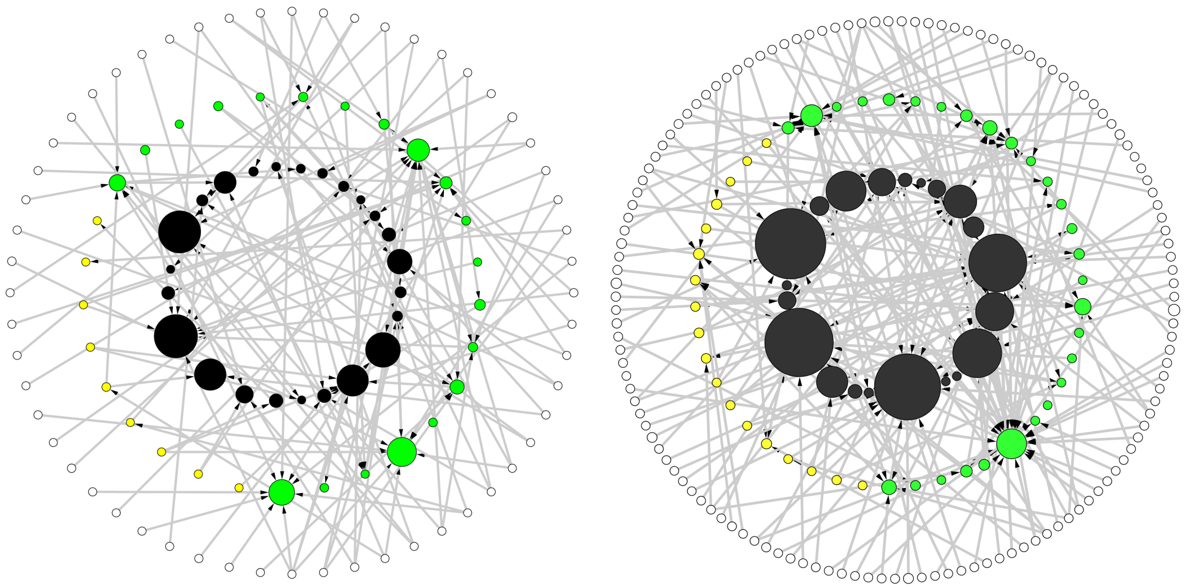
Notes: This table shows the distribution of interbank deposits in years 1862 and 1867. We classified banks into three groups: Philadelphia banks, Pittsburgh banks, and country banks. Then, we grouped the destination of interbank deposits into 5 classes. Using information regarding the amount of interbank deposits deposited in banks in these locations, we then computed the percentage of those deposits against the banks total interbank deposits. We find that Pittsburgh banks began to play more important roles as depository institutions for country banks.
Source: Authors' calculations using data from *Several Banks and Savings Institutions of Pennsylvania* and *OCC National Bank Examination Reports*

with banks in New York City and Philadelphia while increasing their balances with banks in Pittsburgh. This suggests that Pittsburgh banks began to function as major correspondent city as a result of the NBA, though the nominal amounts were relatively smaller in comparison to Philadelphia and New York City interbank deposits.[13]

3.2 Bank Network

Figure 1 depicts interbank networks in 1862 and 1867 and shows how the network changed before and after the NBA. Inner, middle, and outer circles represent banks in central reserve city, reserve cities, and rural areas. We size the circles by calculating the total due-to deposits held by banks to compare between years. By doing so, we can see the relative rank the of each bank in their respective correspondent markets. We see the total number of banks and interbank

[13] We want to note that these values are lower bound estimates due to the data limitation on interbank deposit coverage.



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

NYC PHI PIT country banks

Log Size of Due-To Deposits

Figure 1. Interbank Network This figure visualizes interbank networks in 1862 and 1867. The nodes colored in black, green, yellow, gray, and white indicate New York City banks, Philadelphia banks, Pittsburgh banks, and country banks, respectively. The diameter of each node in color is proportional to the bank's log size of due-to deposits. A link with an arrow indicates a recorded reserve deposit relationship where the arrow points to the deposit receiver. *Source*: Authors' diagrams using data from *Several Banks and Savings Institutions of Pennsylvania* and *OCC National Bank Examination Reports*

deposits links are more numerous as bank relationships expanded between 1862 to 1867. The striking feature of these figures is that the number of banks serving as correspondents in central reserve does not increase even though the number of rural banks expanded sharply. In addition, we see a small number of city correspondents receive a large number of due-to linkages, at both the central reserve and reserve city level indicating a concentration of interbank linkages among banks in financial centers.

In addition, Figure 1 shows that the size of Philadelphia banks and New York bank nodes relative to each other changes starkly. The size of interbank due-to deposits received in 1862 of the largest Philadelphia and New York City banks is quite comparable. In contrast, by 1867 the effect of the NBA demonstrates the immediate concentration of interbank deposits (due-tos) in New York City banks as New York City was designated as the central repository of interbank

Table 4. Herfindahl-Hirschman Index of Interbank Deposits

	All due-tos held by		*PA due-tos held by*	
	(1)	(2)	(3)	(4)
Year	1862	1867	1862	1867
New York City	524	823	177	330
Philadelphia	100	15	416	340
Pittsburgh	0	0	0	8
Other PA	0	0	0	0
Total	624	838	593	678

Notes: This table provides summary information on the concentration of "due-to" deposits, aggregated up to the city level.[14] The concentration is measured using Herfindahl-Hirschman Index (HHI) of the amount the due-tos for individual banks and aggregating these values at the city level. We present this information in two manners. First using all due-to deposits held by the banks in our sample, from the each bank's balance sheet, and second through just due-to deposits of PA Banks, using our individual bank correspondent due-from data. We find that in both cases the concentration of banks increase in New York City relative to Philadelphia.
Source: Authors' calculations using data from *Several Banks and Savings Institutions of Pennsylvania* and *OCC National Bank Examination Reports*

deposits.

Table 4 provides information on the concentration of "due-to" deposits, using Herfindahl-Hirschman Index (HHI) of the amount the interbank deposits held, aggregated up to the city level. We present these measures in two manners. First we calculate these measures by using all due-to deposits held by the banks on the liability side of the balance sheets. These measures help us understand the relative importance of New York City verses Philadelphia with respect to offering correspondent services for all U.S. banks. Second, we calculate these measures by using the amounts due-from banks in New York City, Philadelphia and Pittsburgh listed on the asset side of the respondent banks' balance sheets. These measures help us understand the relative importance of New York City verses Philadelphia with respect to respondent banks in Pennsylvania given, as they typically has one or two major correspondents in financial centers (Weber (2003)).

Columns (1) and (2) of Table 4 present the HHI of due-to interbank deposits held by banks in New York City, Philadelphia, and Pittsburgh respectively. We find a large movement in concentration to New York City; New York City banks grew from a multiple of 5 times larger than Philadelphia banks concentration to a multiple of 50. These results suggest that New York

Table 5. Longest Shortest Path and Degree by Location

	Longest Shortest Path			*In-Degree*			*Out-Degree*		
Year = 1862	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
NYC	-	-	-	**2.7**	10	1	-	-	-
Philadelphia	2.4	5	1	3.4	13	0	**2.1**	5	1
Pittsburgh	1.9	4	1	0.3	1	0	**2.0**	3	1
Country banks	3.0	6	0	0.2	2	0	1.7	5	0
Year = 1867	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
NYC	-	-	-	**5.4**	18	1	-	-	-
Philadelphia	1	1	1	3.1	31	0	**1.0**	2	1
Pittsburgh	1.3	3	1	0.8	5	0	**1.2**	2	1
Country banks	1.8	3	1	0	1	0	1.2	4	1

Notes: This table provides summary statistics for the longest shortest path, in-degree, and out-degree of interbank networks by location and year. We use the Floyd-Warshall algorithm to compute the shortest path between one node to another in a directed graph. 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 length of shortest path decreased for country banks, indicating that bank networks became more centralized. From 1862 to 1867, incoming degrees for NYC significantly increased, indicating that bank linkages became more concentrated in New York City.
Source: Authors' calculations using data from *Several Banks and Savings Institutions of Pennsylvania* and *OCC National Bank Examination Reports*

City and Philadelphia banks served as important due-to banks before the NBA, but New York City banks became the dominant repository post the NBA.

Columns (3) and (4) of Table 4 present the HHI of interbank deposits due-from banks in New York City, Philadelphia, and Pittsburgh respectively. From examinig interbank relationships that appear in these disaggregated data, we see a similar trend in concentration towards New York City. We find that interbank deposit linkages after the NBA became more concentrated in New York City; with the amount of interbank deposits held in Philadelphia going from 4 times larger than to New York City to becoming nearly equivalent. These results suggest that Philadelphia played a less important role in offering correspondent services, compared to before the NBA.

In looking at the linkages more closely, Table 5 provides summary statistics for the distance and degree of bank networks grouped by location in years 1862 and 1867. The distance between banks outside New York City and banks in New York City is measured by the length of longest shortest path. We find the distance from banks outside New York City to banks in New York City deceased.[15] This suggests that the NBA increased the banking system's connectivity to New York City banks. This concentration of Pennsylvania banks to New York City banks is also seen in the rise of the in-degrees for New York City banks. At the same time, out-degrees for Philadelphia and Pittsburgh decreased. This suggests that reserve city banks had a single correspondent in New York City.[16]

4 Model

In this section, we describe a model of a correspondent network. Banks place deposits with each other, thereby create interbank liability relationships. To simulate liquidity crises in the interbank deposit system, we enrich the interbank clearing system in Eisenberg and Noe (2001) and Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) to two periods allowing for both early withdrawals and liquidation. Due to a maturity mismatch between long term illiquid asset investments and demand deposits which may be withdrawn at any time, banks can potentially experience runs, asset liquidation, and possibly default. Liquidity shocks in NYC banks and withdrawal shocks in country banks respectively could trigger systemic early withdrawals and further cause contagious liquidation. Such a framework allows us to study the effect of both top-to-bottom crises and bottom-to-top liquidity crises observed in the National banking era.

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 2 illustrates the model timeline.

At $t = 0$, bank i holds deposit D_i from local depositors. It can also hold interbank deposits from other banks. Denote the interbank deposit that bank j puts to bank i as L_{ji}; bank j is the respondents and i is the correspondent. 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

[15] We believe that these are conservative measures. Although we remove linkages less than 20% of total "due-froms" for each bank, these removed linkages are deposits placed in small country banks.

[16] We discuss the impact of the NBA on individual banks relationships in Appendix V.

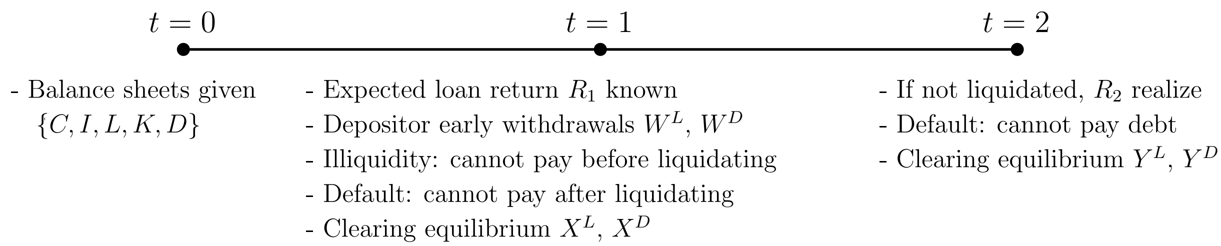


Figure 2. Model Timeline

amounts to $D_i + \sum_j L_{ji}$. The liability is a 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.

Other than deposits, bank i is also endowed with equity capital K_i. The total asset (equity + deposits) is allocated as vault cash C_i, investment in loans and securities I_i, as well as interbank deposits in other banks $\sum_k L_{ik}$. The bank balance sheet items at the initial date are summarized in the following table.

Table 5. Balance Sheet of Bank i at $t = 0$

Asset	**Liability**
Vault cash C_i	Equity capital K_i
Investment in loans and securities I_i	Local deposit D_i
Interbank due-from $\sum_k L_{ik}$	Interbank 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 asset investment matures at the final date $t = 2$ with return rate $R_{i,2}$. Hence, the cash flow from investment at $t = 2$ amounts to $I_i R_{i,2}$. Asset 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 drawn from a multivariate normal distribution with mean ν_t, standard deviation σ_t, and correlation matrix ϱ_t. Here, the loan returns have lower bound zero 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 withdrawal shocks to geographically proximate country banks during crop-moving season.

4.2 Early Deposit Withdrawal

Early withdrawals by local depositors and bank depositors can potentially trigger costly liquidation events. 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 interbank deposits on demand. Denote the interbank clearing repayment matrix at $t = 1$ as X^L where X^L_{ik} denotes the interbank deposit repayment by bank k upon bank i's early withdrawal, $X^L_{ik} \in [0, L_{ik}]$. Similarly, let X^D be the repayment vector to local 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 interbank deposit L_{ik} from k at $t = 1$. Similar notation holds for W^D. Early withdrawals occur when *any of the following conditions hold.*

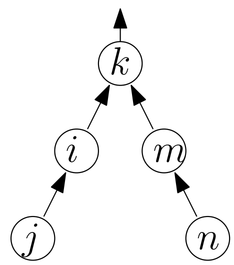
(A) Correspondent has low expected return and high default likelihood. If conditional on $R_{i,1}$, the probability of bank i defaulting at the final date exceeds a threshold $\bar{p}$, all of bank i's depositors choose to withdraw early. This is bank run cause by fundamental shocks.

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

(B) Depositor has liquidity shortage. When respondent bank i experiences early withdrawals by its own depositors and the cash holding C_i cannot cover the liquidity need at $t = 1$, bank i withdraws its own interbank deposits held at other correspondents. This scenario features vertical contagious withdrawals upward along the interbank deposit hierarchy.

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

(C) Correspondent fail to recover its own deposit in full. When bank i's correspondent bank k defaults on i's interbank deposits, bank i may experience difficulty repaying other banks' deposits in full. In this case, depositors of bank i tend to withdraw. This scenario features



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 local 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 local depositors withdraw
- k liquidates and defaults
- i and m liquidate and default, etc...

Figure 3. 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.

vertical contagious withdrawals downward along the interbank deposit hierarchy.

$$\sum_k W_{ik}^L X_{ik}^L < \sum_k W_{ik}^L L_{ik} \Rightarrow W_{ji}^L = 1, \forall L_{ji}^L > 0;\ W_i^D = 1. \tag{5}$$

(D) Other depositors withdraw from the correspondent. From the bank run literature, if there exist local depositors of bank i who withdraw, then all other local depositors of bank i tend to withdraw. This condition characterizes horizontally contagious withdrawals.

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

These events that trigger early withdrawals are summarized in Figure 3. Under such an endogenous liquidity withdrawal framework, as long as one of bank i's depositors withdraws, all of the depositors will withdraw simultaneously, potentially causing illiquidity.

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 *liquidation* and *default* at $t = 1$ based on whether a bank has enough liquidity to pay back debt before and after liquidating the long-term investments.

Definition 1 *Bank i incurs illiquidity at $t = 1$, denoted by $\mathbb{I}_i^l$, when bank i fail to repay early withdrawals in full after withdrawing all interbank deposits held by other banks.*

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

In such an event, bank i liquidates the long-term 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 withdrawals, bank i pays the total nominal debt in full. The bank obtains the remaining cash as equity if the loan has been liquidated; otherwise, the bank obtains the investment return at maturity. However, if the total cash flow is smaller than total early withdrawals 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 (2015) and captures the fact that large shortfalls are considerably more costly than small shortfalls when the firm nearly escapes bankruptcy. When $\xi_d > 1$, each dollar of repayment shortfall creates bankruptcy costs of additional $\xi_d - 1$ dollars, above and beyond the shortfall itself.[17]

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

[17]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).

National Banking era, local depositors have the same seniority as respondent banks.[18] Essentially, local depositors and all respondent 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

$$X^L_{ji} = \frac{W^L_{ji} L_{ji}}{\sum_j W^L_{ji} L_{ji} + W^D_i D_i} \left[\min \left\{ \sum_j W^L_{ji} L_{ji} + W^D_i D_i, H^1_i \right\} \right]^+, \tag{10}$$

where $[\centerdot]^+ = \max\{\centerdot, 0\}$ and guarantees that depositors do not incur further payment when holder defaults. Similarly, payment to local depositors X^D_i is given by

$$X^D_i = \frac{W^D_i D_i}{\sum_j W^L_{ji} L_{ji} + W^D_i D_i} \left[\min \left\{ \sum_j W^L_{ji} L_{ji} + W^D_i D_i, H^1_i \right\} \right]^+. \tag{11}$$

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 deposit repayment X^L, together with the local depositors' repayment X^D defined by (10) - (11) form an* early withdrawal payment equilibrium *of the bank deposit network at $t = 1$.*

4.4 Final Date Payment Equilibrium

The final date payment system consists of all banks that have not experienced illiquidity at t_1 (those with $\mathbb{I}^l = 0$).[19] Whether bank i is able to deliver the full amount of its matured obligations depends on the level of its cash holdings, loan investment return, and whether other banks are able to return its interbank 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 local 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

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

[19] This set of banks might possibly have experienced early withdrawals by depositors but are able to repay the depositors without liquidating loans or taking back all interbank deposits in other banks. In other words, they still remain as lenders in t_2. These banks might also include those who withdrawal deposits from holders due to holders low return, while keeping all other links intact without experiencing illiquidity.

obligations using all assets. The total cash flow at the final date is

$$H_i^2 = \left(1 - \mathbb{I}_i^l\right) \left[I_i R_{i,2} + H_i^1 + \sum_k (1 - W_{ik}^L) Y_{ik}^L \right] \tag{12}$$

Definition 4 *Bank i defaults at $t = 2$, denoted by $\mathbb{I}_i^{d2}$, when at $t = 2$ the total cash flow is smaller than nominal final date debt obligation,*

$$\mathbb{I}_i^{d2} = 1 := H_i^2 < \sum_j (1 - W_{ji}) L_{ji} + (1 - W_i^D) D_i. \tag{13}$$

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 local depositors repayment vector at $t = 2$ are respectively

$$Y_{ji}^L = \frac{(1 - W_{ji}^L) L_{ji}}{\sum_j (1 - W_{ji}^L) L_{ji} + (1 - W_i^D) D_i} \left[\min \left\{ \sum_j (1 - W_{ji}^L) L_{ji} + (1 - W_i^D) D_i, H_i^2 \right\} \right]^+, \tag{14}$$

$$Y_i^D = \frac{(1 - W_i^D) D_i}{\sum_j (1 - W_{ji}^L) L_{ji} + (1 - W_i^D) D_i} \left[\min \left\{ \sum_j (1 - W_{ji}^L) L_{ji} + (1 - W_i^D) D_i, H_i^2 \right\} \right]^+. \tag{15}$$

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 deposit repayments Y^L and local deposit repayment Y^D given by (14) - (15) together with the remaining banks form a* final date payment equilibrium *of the bank deposit network at $t = 2$.*

Following Eisenberg and Noe (2001) and Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), 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 feed the micro-level data of interbank liability structures and balance sheets in 1862 and 1867 into the model 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 based on the types and origins of negative shocks. For the top-to-bottom crises, systemic liquidation and cash suspensions occurred as banks in New York City suffered from correlated losses in loan and security investment. For the bottom-to-top crises, systemic withdrawals and liquidations occurred as banks outside the reserve cities had to withdraw their interbank deposits due to seasonal fluctuations in local demand for money and credit.

Differences in network structure may contribute to the extent that contagion spreads. 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*.[20] Equity capital, K, equals *bank capital* plus *profits and earnings*. Deposit, D, is constructed by adding *deposits* and *bank notes*. Interbank network L is constructed from the data where L_{ij} is the dollar value of interbank deposits for bank i due-from bank j. Finally, we back out the level of loan investments, I, from the balance sheet equation, i.e.,

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

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

We parametrize the remaining model parameters, $\{R_0, \xi_l, \xi_d, \nu_t, \sigma_t, \varrho_t, \bar{p}\}$. We set $R_0 = 1.1$ same for all banks, meaning that on average banks receive 10% return from asset investment. We set as benchmark $\xi_l = 45\%$ and $\xi_d = 145\%$. This means that in an asset liquidation,

[20]For 1862, securities are not required to be put up as collateral, so we categorize all securities as liquid. 6 contains detailed information on regular and standardized balance sheets for state and national banks.

45% of the illiquid asset value can be converted to cash. When an institution defaults, each dollar of payment shortfall creates an additional 45% dollars in bankruptcy costs, above and beyond the shortfall itself.[21] The baseline distribution of asset 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).[22] Finally, we set the value of $\bar{p}$, the threshold of expected default probability to trigger depositor early withdrawals, to 20% and check for robustness.

5.2 Measures of Financial Stability

To quantify the impact of changes in 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 (2015) 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-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 a fraction of θ_l banks liquidating simultaneously. We also compute the probability of joint default at $t = 1$ and $t = 2$ when there are more than a

[21] These values are set in line with Glasserman and Young (2015).

[22] We look at a panel of banks in 1872 - 1875 and compute the mean and volatility of 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.

fraction of θ_d banks defaulting simultaneously $\mathbb{P}_d^{joint}$.

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

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.[23]

The second set of measures look at the expected percentage of banks liquidating and defaulting, denoted by respectively P_l, P_d.

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

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_d denotes 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,

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

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

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

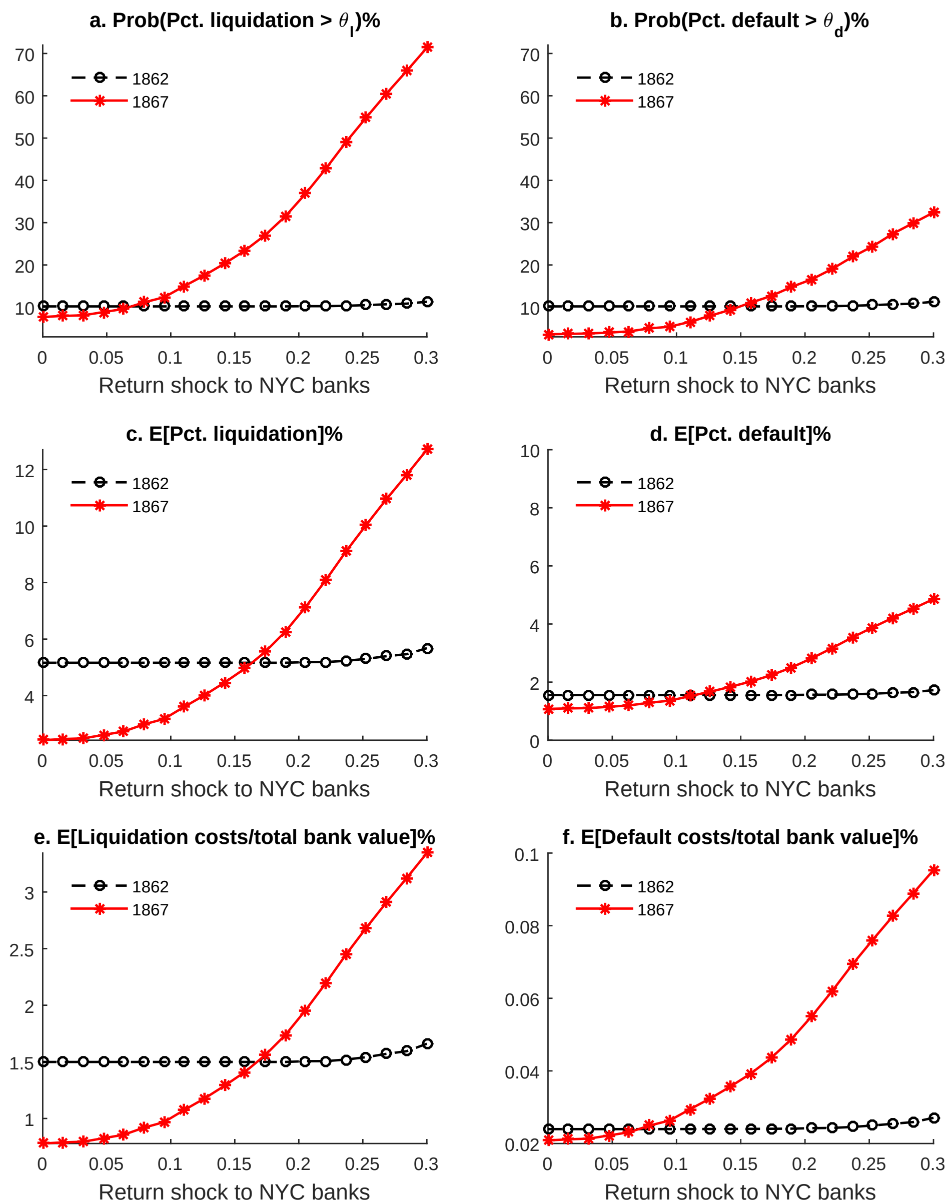


Figure 4. Top-to-Bottom Crises: systemic risk measures This figure shows the financial stability measures when we shock all NYC banks with lower expected loan return rate R_1 by reducing ν_1 of all NYC banks and increasing the return correlation among all NYC banks such that $\rho_1^{NYC} = 0.2$. The horizontal axis indicates the level of asset return reduction $\Delta\nu_1$ for all NYC banks. Panels a-f show respectively the probability of a systemic liquidation event $\mathbb{P}_l^{joint}$, the probability of a systemic default event $\mathbb{P}_d^{joint}$, the expected percentage of banks liquidating P_l, the expected percentage of banks defaulting P_d, the expected liquidation cost proportional to the bank loan size normalized by total value of the banking sector V_l, and the expected defaulting cost proportional to asset shortfall normalized by total value of the banking sector V_d. 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).

5.3 Top-to-bottom Crises

We begin by an analyzing the impact of banking crises originating from New York City banks. In the simulation, we shock all NYC banks with correlated lower expected loan return rate R_1 by reducing ν_1 of all NYC banks and setting the return correlation among all NYC banks such that $\rho_1^{NYC} = 0.2$. This captures the scenario when NYC banks have correlated expected loss in loan and security investment, which can trigger withdrawals. We then plug in the balance sheet data and the linkage matrix empirically observed in 1862 and 1867. For each shock size $\Delta\nu_1$, we take 5000 random draws. For each of these simulated scenario, we compute the two-period payment equilibrium. Particularly, we adopt an iterative algorithm to obtain the fixed point solution of W^D, W^L, X^L, X^D.[24] Given the computed payment equilibrium and liquidation/default indicators, we can then 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 magnitude of negative liquidity shocks for top-to-bottom crises. When the magnitude of negative shocks are within a threshold, the 1867 network outperforms in resilience. However, as the magnitude of shock becomes larger, systemic risk measures in 1867 increase exponentially whereas those for 1862 are less responsive. Figure 4 summarizes the main results. The six panels each illustrates $\mathbb{P}_l^{joint}, \mathbb{P}_d^{joint}, P_l, P_d, V_l, V_d$ for 1862 in black and for 1867 in red. All measures are expressed as percentage. The horizontal axis indicates the level of loan return reduction $\Delta\nu_1$ for all NYC banks. When the shock size is small, say the expected asset investment return is reduced by 5% (equivalently the expected asset return at final date is between 5% to 10%), all systemic risk measures for 1867 lie below those of 1862. However, with a shock size as large as 0.3, or equivalently when NYC banks expect an investment loss of 20%, all measures of 1867 exceed those of 1862. The exact threshold values depend on the specific measure we focus on, either liquidation or default, joint failures or aggregate cost.

[23] 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 to 5%.

[24] Notice that self-fulfilling runs can potentially cause multiple equilibria. For example, all depositors withdrawing is a stable equilibrium under conditions (B) and (D). In the simulation, we rule out such self-fulfilling runs and only consider withdrawals that are due to either fundamentals or contagions.

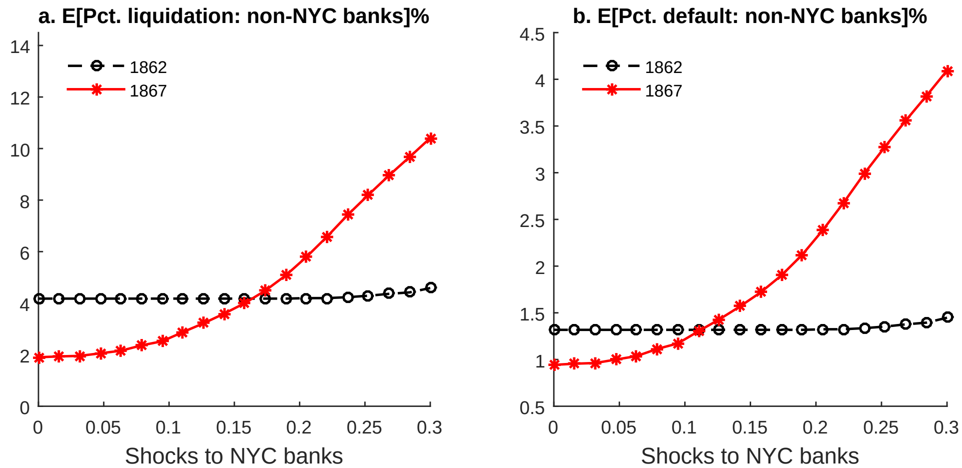


Figure 5. Top-to-Bottom Crises: contagion This figure shows contagion measures when we shock all NYC banks with lower expected loan return rate R_1 by reducing ν_1 of all NYC banks and increasing the return correlation among all NYC banks such that $\rho_1^{NYC} = 0.2$. The horizontal axis indicates the level of asset return reduction $\Delta\nu_1$ for all NYC banks. Panels a-b show respectively the expected percentage of liquidating and defaulting banks that are not located in NYC and thus are not directly shocked with lower expected investment returns. 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).

5.4 The Mechanism: contagion and the network structure

The reserve hierarchy established by the NBA is more robust to mild negative shocks to NYC banks. The underlying mechanism is due to a reduction in contagion. Figure 5 shows the contagion measures when we simulate top-to-bottom crises. The two panels illustrate respectively the expected percentage of liquidating and defaulting banks that are not located in NYC. These banks are not directly shocked; hence, most likely their liquidation and default are caused by their direct or indirect interbank linkages with the shocked NYC banks. When the expected asset investment return of NYC banks is reduced only by a small magnitude, say 5%, a more concentrated network reduces contagion. This comes from two effects. First, as the length of counterparty chains gets shorter (from an average of 3 in 1862 to 1.8 in 1867), chances of contagion from indirect counterparties are reduced. Second, the concentration increases the number of respondents each correspondent has. This facilitates risk diversification so that when the correspondent suffers from asset loss, only a small fraction of the loss is passed on to individual respondents because of the *pro rata* payment rule.

However, the system becomes prone to contagious liquidation once the negative shock becomes significant enough. Under large investment loss, NYC banks default on their bank depositors, thereby causing runs at these depositing banks (as per condition (C)). A large enough shortfall can cause systemic liquidation and default at these depositing banks. In this case, the negative shocks propagate to the majority of connected respondents. As such, the concentrated bank relationships acted as a mechanism for contagion. In Figure 5, when the NYC banks expect a loss in investment of 20% (horizontal axis is at 0.3), the percentage of non-NYC banks liquidating or defaulting almost matches that in Panels c and d of Figure 4. This shows that, as we increase return shocks to NYC banks, the sharp increase in systemic risk measures in 1867 can be mostly attributed to contagion.

In particular, we classify contagion channels based on whether liquidation propagates upward or downward along the reserve hierarchy. A downward withdrawal contagion occurs when a bank suffers from depositors' withdrawals because its correspondent up the hierarchy defaults and fail to repay its interbank deposits in full (condition (C)). Similarly, upward withdrawal contagion occurs when a bank experiences runs and liquidity shortage and hence has to withdraw interbank deposits from its own city correspondents (condition (B)). Figure 6 further decomposes the contagion measures into downward (panel a) and upward (panel b). Consistent with the above mechanism, top-to-bottom crises under large-sized shocks are mainly due to downward withdrawal contagion from banks in NYC at the top of the pyramid towards their depositors and depositors' depositors, etc.

This 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).[25]

5.5 Bottom-to-top Crises

Alternatively banking crises could start when a large number of country banks began to withdraw from their city correspondents and thereby overwhelming the ability of correspondents to satisfy their liquidity demands. We simulate these types of crises by drawing a set of country

[25] 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.

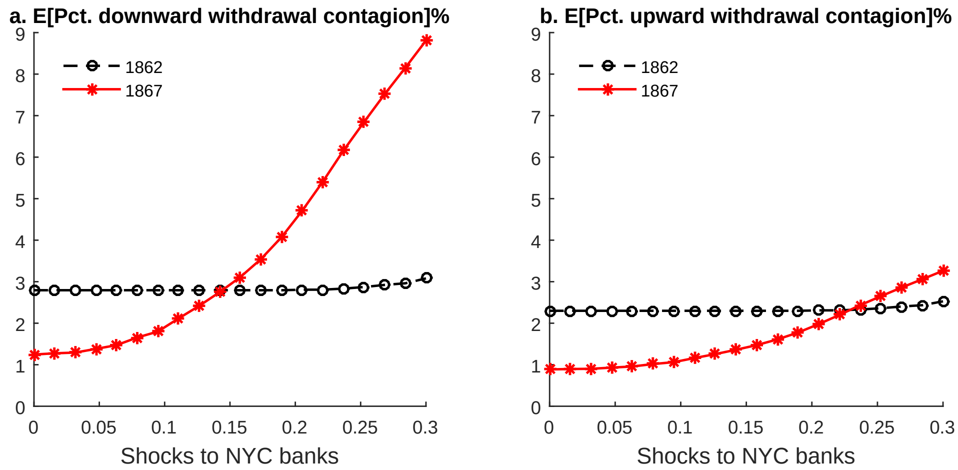


Figure 6. Top-to-Bottom Crises: contagion channels This figure shows the channels of contagious withdrawals when we shock all NYC banks with lower expected loan return rate R_1 by reducing ν_1 of all NYC banks and increasing the return correlation among all NYC banks such that $\rho_1^{NYC} = 0.2$. The horizontal axis indicates the level of loan return reduction $\Delta\nu_1$ for all NYC banks. Panels a-b show respectively the expected percentage of banks suffering from depositors' withdrawals because their correspondents are defaulting (condition C downward contagious withdrawals), and because their depositors have liquidity shortage (condition B upward contagious withdrawals). 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).

banks and set these banks exogenously with $W^D = 1$. For each given country bank withdrawal probability, we take 5000 draws from a multivariate correlated binary distribution. For each of these simulated scenario, a certain fraction of country banks are exogenously set with $W^D = 1$. Local depositors withdraw from these exogenously shocked country banks on top of the four withdrawal conditions in section 4.2. We then compute the two-period payment equilibrium via iteration while ruling out self-fulfilling runs. Given the computed payment equilibrium and liquidation/default indicators, we can then compare the financial stability measures in 1862 and 1867. Results show that after the National Banking Acts the banking system became more robust to shocks originating from country banks as long as the percentage of country banks experiencing withdrawals is not very large (close to 100%).

Figure 7 shows the financial stability measures for bottom-to-top crises. The horizontal axis indicates the exogenous probability of country banks experiencing withdrawals from local depositors. The six panels each illustrates $\mathbb{P}_l^{joint}, \mathbb{P}_d^{joint}, P_l, P_d, V_l, V_d$ for 1862 in black and for 1867 in red. All the measures are expressed as percentage. As long as the probability of country bank experiencing withdrawals is not too large, all systemic risk measures for 1867 lie below those for 1862. Only when the probability is large enough (say close to 100%), some of the systemic risk measures are higher for 1867. Even if interbank links can pass on contagious withdrawals upward along the pyramid, the financial center banks tend to hold enough liquid assets and can diversify among depositors such that they do not default after liquidation.

5.6 Implications

To summarize the quantitative analysis, we feed the micro-level data of interbank liability structures and balance sheets in 1862 and 1867 into the interbank network model and quantify how such a change in L affects the resilience of the interbank system. Results show that the Acts induced a "*robust-yet-fragile*" nature of the more centralized bank networks. The post-Acts network is more robust against both small-sized liquidity shocks to financial center banks and seasonal withdrawals to country banks, but is more vulnerable when the negative shocks are large in size. For top-to-bottom crises, as long as the magnitude of negative shocks are within a threshold, the post-Acts network is more stable; when the losses are large enough to trigger default at financial center banks, linkages start serving as a channel for systemic contagion. For bottom-to-top crises, the post-Acts network is in general more resilient as long as the fraction of country banks simultaneously experiencing seasonal withdrawals is not very large. While linkages can pass on contagious withdrawals upward along the pyramid, the financial center banks tend to hold enough liquid assets to prevent them from defaulting. Overall the impact of the Acts on systemic risk favored increasing the systemic nature of top-to-bottom crises while reducing bottom-to-top crises.

These results not only confirm the theoretical finding of Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) and Gai and Kapadia (2010) but also add to the discussion in identifying the source of bank panics in the National Banking era. Many have long believed that bank panics originated from banks outside financial centers because they had to accommodate the seasonal fluctuations in the demand for money and credit. For instance, Kemmerer (1910) reported that the seasonal fluctuations in money and credit demand were the underlying causes of the financial crises since they cause banks outside financial centers to withdraw their interbank balances in spring and fall. However, recently, economists have shown that unexpected financial shocks in

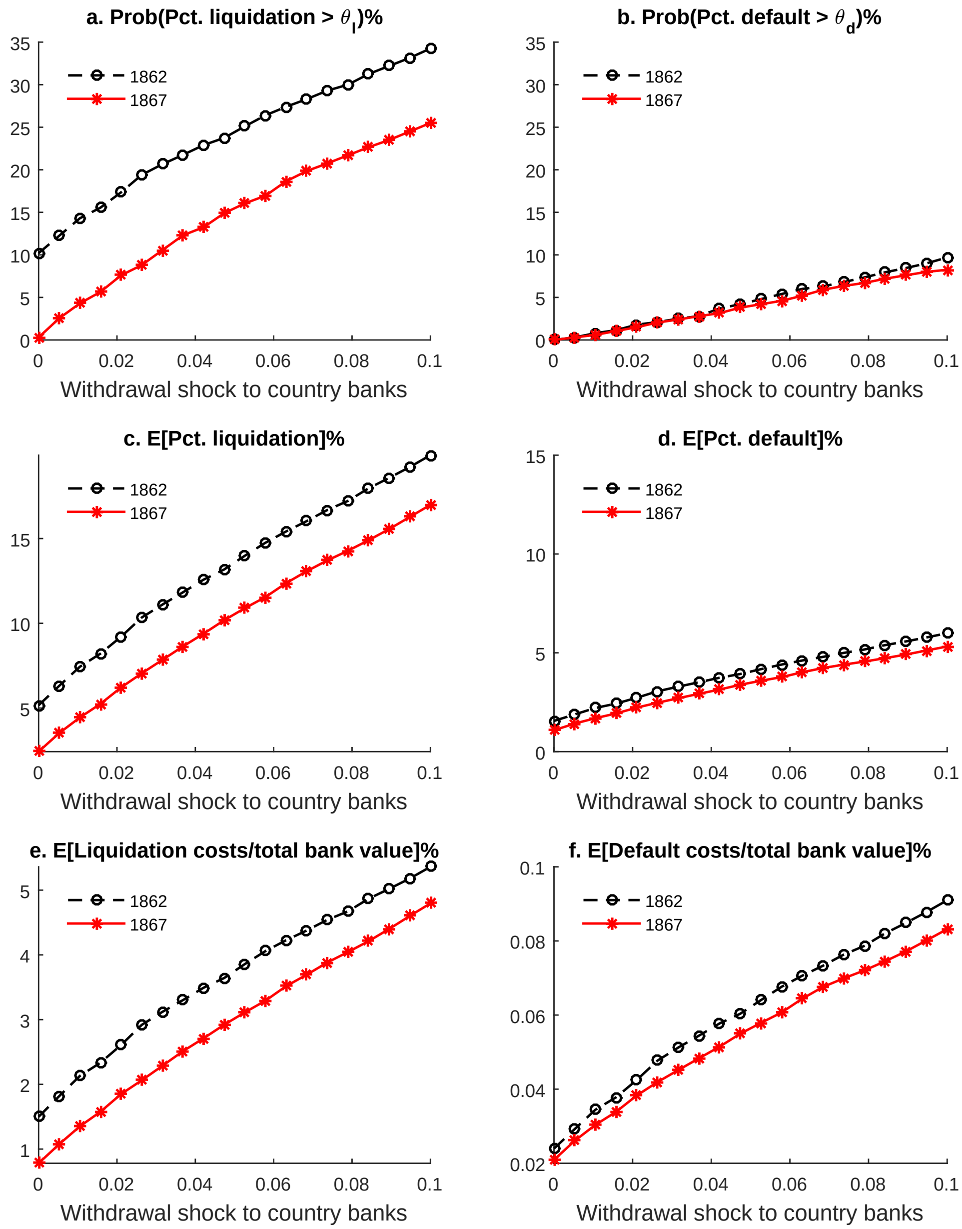


Figure 7. Bottom-to-Top Crises: systemic risk measures This figure shows the financial stability measures when we shock all country banks with an exogenous probability of suffering from withdrawals from local depositors. The horizontal axis indicates the probability of suffering from withdrawals for all country banks. Panels a-f show respectively the probability of a systemic liquidation event $\mathbb{P}_l^{joint}$, the probability of a systemic default event $\mathbb{P}_d^{joint}$, the expected percentage of banks liquidating P_l, the expected percentage of banks defaulting P_d, the expected liquidation cost proportional to the bank loan size normalized by total value of the banking sector V_l, and the expected defaulting cost proportional to asset shortfall normalized by total value of the banking sector V_d. 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).

New York City may have been a more important source of the financial crises. They argue that the timing of major banking panics did not coincide with the time of monetary stringency induced by seasonal cycles. In addition, the country bank closings in the interior were few in number, region-specific, and too localized geographically to have national-wide effects.

Our results suggest that liquidity shocks to financial center banks may have been a much bigger threat to the stability of the financial system. Our result is supported by the fact that major panics, post the National Banking Act, originated from New York City rather than the interior. This fact suggests that financial center banks were resilient to financial distress from the interior whereas the same was not true for interior (country) banks when New York City banks were under financial distress. In other words, the importance of financial shocks from the interior may have been overemphasized.

6 Conclusion

In this paper, we examine how the National Banking Acts (NBA) changed the structure of bank networks and affected systemic risk. The NBA created a reserve pyramid by requiring banks to keep the amount of reserves based on their location and mandated New York City as a financial center of the nation. We find that the interbank linkages became more concentrated in a small number of banks in financial centers, thereby creating financial institutions with greater systemic importance. Then, we examine how changes in the structure of the interbank network affected systemic risk. Quantitative results show that the bank networks became "*robust-yet-fragile*." Greater concentration of linkages leads to a less fragile interbank network in general; however, system wide contagion can occur if the banking system experiences large shocks at the highly interconnected financial center banks.

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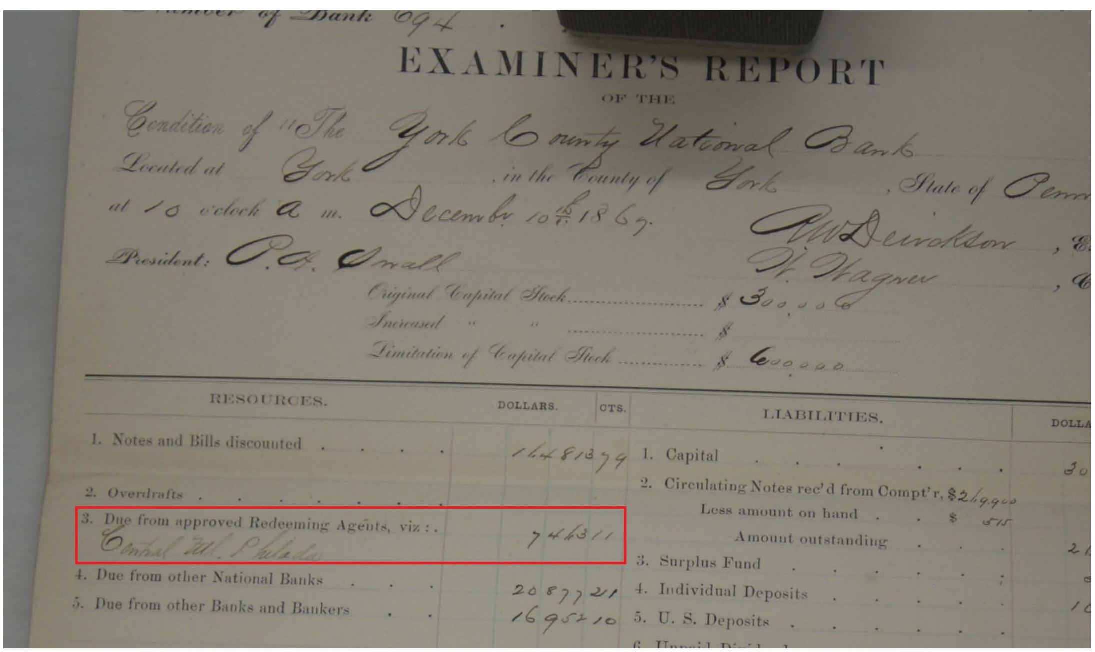
Appendix I: Sample Data

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 I.1. Pennslyania State Bank Report: York County Bank This table contains all the corresponding banks that the bank had deposits with.


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 $300000

Increased " " $

Limitation of Capital Stock $600000

RESOURCES.	DOLLARS.	CTS.	LIABILITIES.	DOLLA
1. Notes and Bills discounted	164813	79	1. Capital	
2. Overdrafts			2. Circulating Notes rec'd from Compt'r, $249900; Less amount on hand $515; Amount outstanding	
3. Due from approved Redeeming Agents, viz : Central Ntl. Philada	7463	11	3. Surplus Fund	
4. Due from other National Banks	20877	21	4. Individual Deposits	
5. Due from other Banks and Bankers	16952	10	5. U. S. Deposits	

Figure I.2. 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: Balance Sheets Standardization

Table II.1. State Bank Balance Sheet Structure

Assets	Standardized
Gold and silver in the vault of the bank	Cash
Current notes, checks, and bills of other banks	Cash
Uncurrent notes, checks, and bills of other banks	Cash
Other obligations of other banks	Due from
Bills and notes discounted, (not under protest)	Loans
Bills and notes discounted, (under protest)	Loans
Mortgages held and owned by the bank	Loans
Assessed value for 186- of the real estate bound by said mortgages	Loans
Judgments held and owned by the bank	Loans
Real estate held and owned by the bank	Loans
Due from solvent banks	Due from
Due from insolvent banks	Due from
Public and corporate stocks and loans	Liquid securities
Bonds held by the bank	Liquid securities
Treasury notes	Liquid securities
Claims against individuals or corporations, disputed or in controversy	Loans
All other debts and claims either due or to become due	Loans
Expenses	Other
Value of any other property of the bank, as the same stands charged on the books, or otherwise	Other
Liabilities	**Standardized**
Capital stock actually paid in	Capital
Deposits	Deposits
Certificates of deposit	Deposits
Due to the Commonwealth	Other
Due to banks	Due to
Due to individuals	Deposits
Claims against the bank in controversy	Other
Surplus, contingent, or sinking fund	Surplus
Earnings	Surplus
All other items of indebtedness not embraced in foregoing specifications	Other

Notes: This table provides information on regular and standardized balance sheets for state banks. Source: State Banking Reports.

Table II.2. National Bank Balance Sheet Structure

Assets	Standardized
Loans and discounts	Loans
Overdrafts	Loans
U.S. bonds dep'd to secure circulation	Illiquid securities
U.S. bonds dep'd to secure deposits	Illiquid securities
U.S. bonds and securities on hand	Liquid securities
Other stocks, bonds, and mortgages	Liquid securities
Due from approved redeeming agents	Due from
Due from other national banks	Due from
Due from other banks and bankers	Due from
Real estate, furniture, and & c	Other
Current expenses	Other
Premiums	Other
Checks and other cash items	Cash
Bills of national banks	Cash
Bills of other banks	Cash
Specie	Cash
Fractional currency	Cash
Legal tender notes	Cash
Compound interest notes	Cash
Liabilities	Standardized
Capital stock	Capital
Surplus fund	Surplus
Undivided profits	Surplus
National bank notes outstanding	Notes
State bank notes outstanding	Notes
Individual deposits	Deposits
United States deposits	Deposits
Deposits of U.S. disbursing officers	Deposits
Due to national banks	Due to
Due to other banks and bankers	Due to
Amount due, not included under either of the above headings	Other

Notes: This table provides information on regular and standardized balance sheets for national banks. Due from approved redeeming agents, checks and other cash items, specie, fractional money, legal tender notes, and compound interest notes counted toward legal reserves. (From The National Bank Acts, Banker's Magazine, 1875) Source: National Bank Examiners' Reports and Report of the Comptroller of the Currency.

Appendix III: Bank Networks on the Map

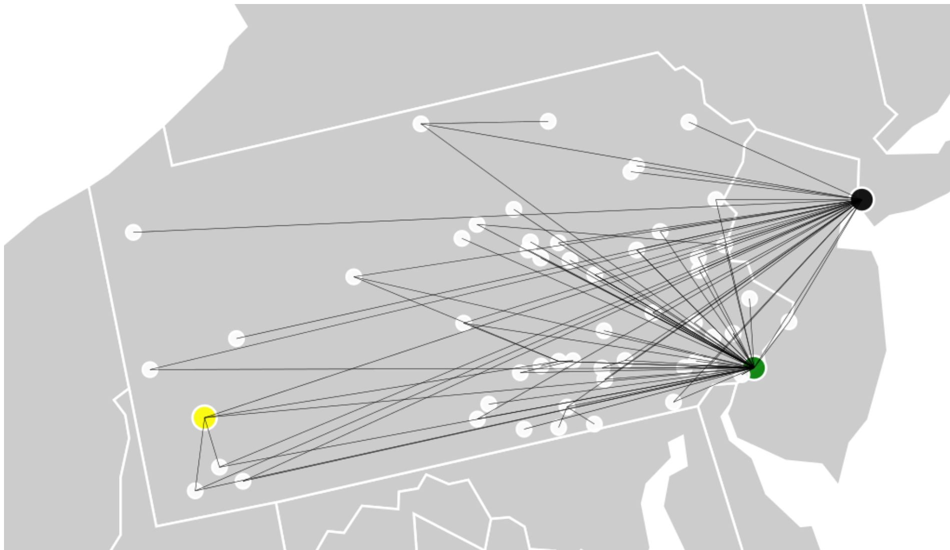


Figure III.1. 1862 Bank Networks on the Map This figure plots the interbank relationships by aggregating bank-level relationships up to the town/city level, represented by a dot. Dot colors correspond to the country bank locations (grey), Pittsburgh (yellow), Philadelphia (green), and New York City (Black). We can see a high density of links going to New York City and Philadelphia, with a few links going to other locations.

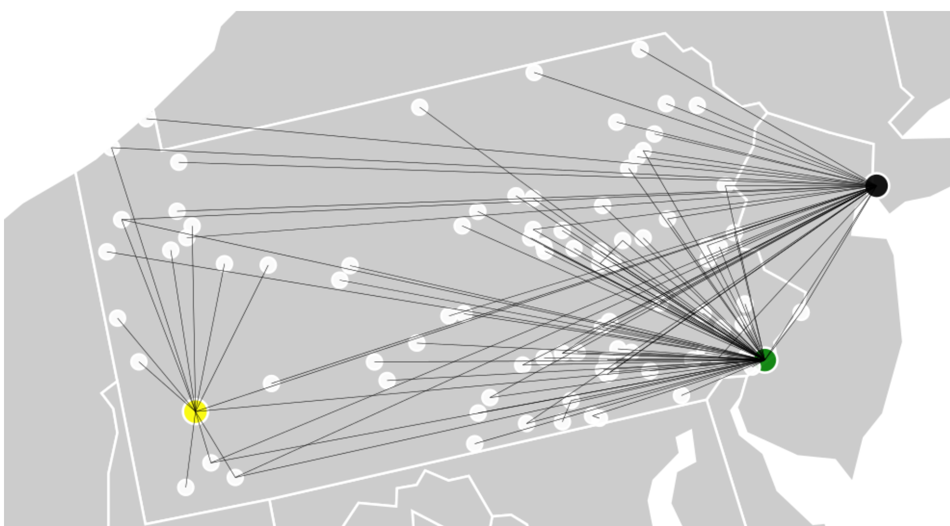
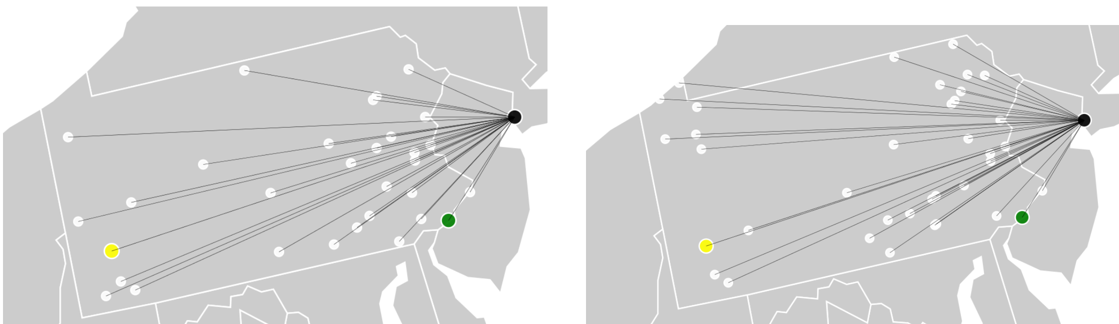
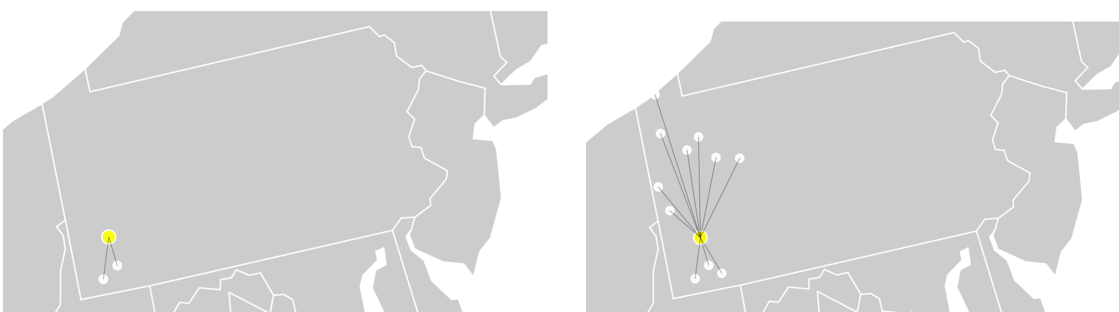


Figure III.2. 1867 Bank Networks on the Map This figure plots the interbank relationships by aggregating bank-level relationships up to the town/city level, represented by a dot. Dot colors correspond to the country bank locations (grey), Pittsburgh (yellow), Philadelphia (green), and New York City (Black). We can see a higher density of links going to New York City, Philadelphia, and Pittsburgh, in contrast to Figure II.1.

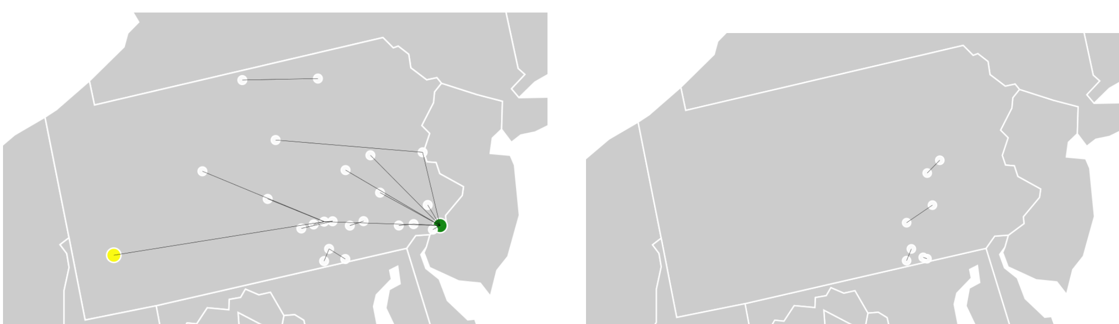


(a) 1862 New York City (b) 1867 New York City

(c) 1862 Philadelphia (d) 1867 Philadelphia



(e) 1862 Pittsburgh (f) 1867 Pittsburgh



(g) 1862 Other Locations (h) 1867 Other Locations

Figure III.3. Compare Bank Networks by Location This panel of figures plots the interbank relationships by aggregating bank-level relationships up to the town/city level, represented by a dot. Dot colors correspond to the country bank locations (grey), Pittsburgh (yellow), Philadelphia (green), and New York City (Black). Each right and left figure plots the "due from" relationships of New York City (a,b), Philadelphia (c,d), Pittsburgh (e,f), and other locations (g,h) in 1862 (right) and 1867 (left). We observe higher concentration of relationships to central reserve and reserve cities in the left half of the panel verse the right.

Appendix IV: The Civil War's Impact on Bank Balance Sheets and Interbank Deposits

Concerns regarding the influence of the Civil War on the interbank network have been mentioned, as the U.S. payments system had suffered from panics prior to National Banking Acts. These panics occurred because holders of bank liabilities, notes or deposits, demanded that banks convert their debt claims into cash in sufficient numbers that the banks suspend convertibility or acted collectively to avoid suspension by issuing clearinghouse loan certificates (Calomiris and Gorton (1991)). Given that banks outside city centers considered interbank deposits as a source of liquidity, the difficulty of these banks to access their interbank deposits in city correspondents could have forced banks to consider a different set of correspondents. In this appendix we describe in detail the impact the Civil War had on (1) bank balance sheets, (2) deposit relationships and (3) the structure of the interbank deposit network by examining how the banking system changed between 1859 and 1862. This analysis is meant to provide a vehicle to help differentiate the impact that the Civil War had versus the National Banking Act.

A.IV.1 Changes in Balance Sheet Data

Using the balance sheet data from *Reports of the Several Banks and Savings Institutions of Pennsylvania* we examine how state banks and savings institutions in Pennsylvania, for the years of 1859 and 1862, transitioned due to the financial crises during the Civil War period. While the state banking department at this time did not impose any reserve requirement regulations, banks still maintained liquid balance sheet structures. Table IV.1 shows how the Pennsylvania state banks were liquid, holding on average somewhere between 20 and 30 percent of their assets in the form of liquid assets. Interbank deposits accounted for about two-thirds of these liquid assets. The other major asset category is loans, which accounted for about 60 and 70 percent of assets.

We see the impact of the Civil War, reflected in both the asset and liability sides of balance sheets. On the asset side, banks increased their holdings of liquid assets. Interestingly, they increased the holding of interbank deposits although cash payments were suspended by banks in New York City and elsewhere. On the liability side, the equity ratio fell as the amount of bank capital declined, probably because holding bank shares became risky during the periods of panic due to the double liability structure.

Table IV.1. Summary Statistics

	All Banks			*Philadelphia*			*Pittsburgh*			*Country Banks*		
Year = 1859	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets												
Cash	79	0.112	0.057	20	0.139	0.04	7	0.126	0.043	52	0.1	0.06
Notes	79	0.047	0.05	20	0.101	0.066	7	0.041	0.029	52	0.026	0.023
Interbank Deposits	79	0.073	0.063	20	0.04	0.021	7	0.02	0.005	52	0.093	0.068
Loans	79	0.723	0.103	20	0.673	0.07	7	0.78	0.066	52	0.734	0.111
Total Assets ($)	79	$870,437	$1,006,896	20	$1,884,910	$1,473,122	7	$1,261,635	$598,477	52	$427,594	$274,640
Against Total Liabilities												
Equity	79	0.41	0.108	20	0.344	0.07	7	0.571	0.057	52	0.413	0.101
Due to	79	0.033	0.031	20	0.057	0.04	7	0.023	0.011	52	0.025	0.023
Bank Notes	79	0.291	0.147	20	0.119	0.05	7	0.212	0.055	52	0.368	0.115
Deposits	79	0.242	0.15	20	0.467	0.068	7	0.177	0.048	52	0.165	0.076
Total Deposits ($)	79	$284,877	$459,107	20	$847,792	$622,936	7	$241,138	$182,326	52	$74,259	$64,298
Year = 1862	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets												
Cash	90	0.127	0.084	20	0.178	0.072	7	0.199	0.079	63	0.102	0.076
Notes	90	0.07	0.069	20	0.124	0.098	7	0.075	0.069	63	0.052	0.047
Interbank Deposits	90	0.145	0.103	20	0.034	0.042	7	0.121	0.043	63	0.182	0.095
Loans	90	0.6	0.138	20	0.613	0.102	7	0.48	0.167	63	0.609	0.14
Total Assets ($)	90	$1,227,290	$1,499,741	20	$2,903,093	$2,277,304	7	$2,128,571	$791,021	63	$595,147	$418,574
Against Total Liabilities												
Equity	90	0.278	0.087	20	0.24	0.055	7	0.36	0.065	63	0.281	0.091
Due to	90	0.03	0.053	20	0.091	0.085	7	0.006	0.006	63	0.014	0.016
Bank Notes	90	0.342	0.22	20	0.132	0.095	7	0.392	0.177	63	0.403	0.213
Deposits	90	0.319	0.2	20	0.507	0.093	7	0.225	0.111	63	0.27	0.197
Total Deposits ($)	90	$459,325	$786,952	20	$1,475,005	$1,179,826	7	$478,389	$328,128	63	$134,769	$110,162

Source: Authors' calculations.

Note: The table is created with quarterly level balance sheets. Ratios are shown in percent.

Table IV.2. Information on interbank correspondent relationships

Item	All Deposits		Major Deposits	
	1859	1862	1859	1862
Banks in sample	78	89	78	89
Total banks in PA	81	91	81	91
Relationships per bank				
Average	14.1	13.2	1.2	1.4
Median	11	12	1	1
Low	1	1	0	0
High	54	43	3	3
Number of related banks				
Pennsylvania	152	188	34	25
Non-Pennsylvania	223	129	21	29
- Union States	127	97	20	29
- Confederate States	96	32	1	0
Total Number of States	25	21	7	6

A.IV.2 Changes in Corespondent Deposit Data

Table IV.2 summarizes the disaggregated correspondent information of the banks. Rows 3-11 of the Table IV.2 show that Pennsylvania banks had relationships with a large number of banks, on average holding amounts due with 14 other banks.[26] We see that these numbers are relatively constant over the two periods and that this holds for both all and major deposits, suggesting that the number of relationships was particularly not effected.

Though the number of relationships did not change, the number of debtor banks did decreased. From Mitchell (1899), we know that if Pennsylvania banks would have suffered the loss of relationships with southern states in 1860, as the first panic of the war lead to the withdrawal of most interbank deposit in Union sates by banks in Confederate states and vice versa. Rows 8-11 of Table IV.2 shows that, Pennsylvania banks maintained a large number of relationships within the state but the amounts due from more other state banks decreased to nearly half of its original quantity. The majority of this decrease coming form banks located in the Confederate states. Though its worth noting that major deposits relationships were not impacted, as Pennsylvania Banks had a preference for Union state banks in 1859.

Table IV.3 breaks these down the distribution of major interbank deposits banks by location. In 1859, Philadelphia banks maintained a large portion of their deposits in Pennsylvania, holding a half of them in Philadelphia and the other half in country banks in Pennsylvania. Philadelphia banks also maintained a large portion of their deposits outside Pennsylvania. Pittsburgh banks held their interbank deposits across New York (almost 20 percent), Philadelphia (about 25 percent), but maintained the most of their deposits in local business hubs outside Pennsyl-

[26]The median number was approximately 11, and the range was between 1 and 54.

Table IV.3. Distribution of Interbank Deposits

	Philadelphia			Pittsburgh			Country Banks		
Year = 1859	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Assets									
New York City	4	0.07	0.045	6	0.215	0.142	35	0.229	0.3
Philadelphia	18	0.229	0.243	7	0.216	0.219	48	0.442	0.329
Pittsburgh	5	0.005	0.007	1	0.354	.	18	0.238	0.327
Country Banks in PA	19	0.377	0.171	2	0.136	0.164	45	0.265	0.274
Other U.S.	19	0.372	0.152	7	0.503	0.266	34	0.177	0.237
Year = 1862	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
Against Total Interbank Deposits									
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
Country Banks in 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

Source: Authors' calculations. *Notes:* The table is with bank balance sheets at the annual frequency due to the availability of disaggregated information on interbank deposits at the fourth quarter of each year. Ratios are expressed in percent.

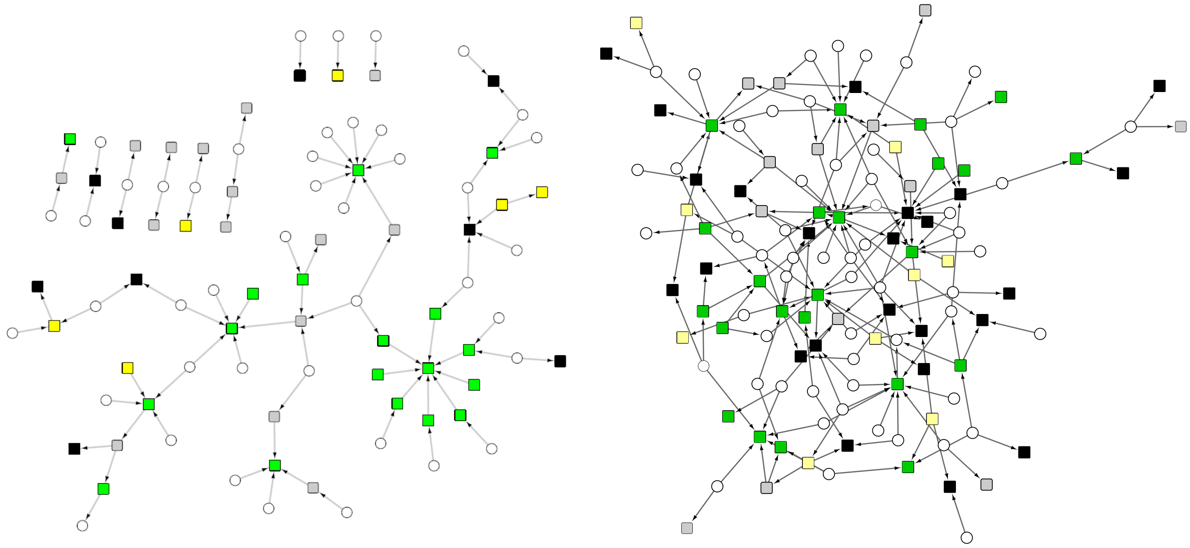
vania (around 50 percent). Country banks spread their interbank deposits across New York, Philadelphia, Pittsburgh, but maintained a large portion of their interbank deposits in other local business hubs and elsewhere (37 percent).

By 1862, we do see some major changes in the distribution of interbank deposits. All three types of banks began holding large portions of their interbank deposits in New York City and reduced holding of their interbank deposits in other local business hubs and elsewhere. The desire of Pennsylvania banks to hold more deposits in New York City banks might have originated from New York banks ability to collectively act to prevent large crises through their clearinghouse.[27]

A.IV.3 Changes in the Interbank Deposit Network

The pre-Civil War network of deposits, shown in Figure IV.1, shows the network was heavily dependent on distance and transportation routes with single links to cities along these routes (Weber (2003)). The structure was shows a heavily centralized system, with a small number of highly connected Philadelphia and New York City banks mainly receiving deposits. While the majority of the deposits were sent by the country banks to banks in financial centers there was

[27]During financial crises, clearinghouses attempted to stop information contagion which if unchecked could cause bank runs. Banks runs occur when depositors lose confidence in the banking system and demand large-scale transformations of deposits into cash. Depositors demand cash because they have received information that changes the perceived riskiness of demand deposits. Since depositors could not distinguish which banks were weak and which were not, they ran on all banks (Gorton (1985)). Clearinghouses were institutional responses to both the possibility and the actuality of such information externalities.



(a) Pennsylvanian Banks 1859 (b) Pennsylvanian Banks 1862

NYC PHI PIT local hubs country banks

Figure IV.1. Bank Major Deposit Network This figure visualizes the bank reserve deposit networks in 1859 and 1862. 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.

also a proportion of deposits put to local transportation and money hubs, such as those located in Harrisburg.

By 1862, the number of banks receiving deposits in Philadelphia and New York City expanded, creating a diversified network structure of major deposits, making the once core-periphery like structure seen like a tangled "hairball". Table IV.4 tabulates the distribution of banks by their roles in the deposit network by location. We group banks by location in New York City, Philadelphia, Pittsburgh, Harrisburg, and other country banks. When we look at the distribution of banks that served as depositors only, deposits takers only, intermediaries (both receive and send deposits), as well as none of the above (isolated), we see a dramatic shift in where major deposits where finally held. Banks in Philadelphia, Pittsburgh, and Country banks which once were deposit-takers only became intermediaries. New York City banks became the final major deposit holders for the entire state of Pennsylvania, expect for a few banks in Harrisburg. This transition in preference for keeping deposits and clearing local to one oriented to New York City showed a desire for increased security rather than local connivance.

This finding suggest that the hierarchical structure of deposits and the roles major city banks played had begun to form out prior to National Banking Acts. Though by 1867, the

Table IV.4. Roles in the Interbank Deposit Network by Location

	Obs	Depositor only	Deposit-taker only	Intermediary	Isolated
Year = 1859					
Philadelphia	18	3	7	8	2
Pittsburgh	7	3	3	1	0
Harrisburg	5	0	3	2	0
Country banks	51	41	5	5	1
Year = 1862					
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					
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 depositors only, deposit-takers only, intermediaries, and isolated. "Depositor only" refers to banks that only deposit 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 from other banks, i.e. they are at the end of a path in a network. "Intermediary" refers to banks that both deposit to other banks and take deposits 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 or take with other banks, i.e. they do not have have any vertex in the network. From 1859 to 1862, the role of banks in the deposit network became more specialized by location: more New York City banks grew to be the dominant deposit-takers and Philadelphia banks became intermediaries, whereas Pittsburgh, Harrisburg and country banks did not see the same growth. From 1862 to 1867, the role of banks in the deposit network became further specialized by location: Philadelphia and Pittsburgh banks became intermediaries, whereas country banks evolved into mostly depositors only.

role of banks in the deposit network became further codified, such that both Philadelphia and Pittsburgh banks became larger intermediaries, whereas country banks continued to evolve into depositors-only. Notably, the local hubs in as Harrisburg banks, seen as a safe haven in 1862, became depositor-only banks in 1867.

Additionally we see the 1862 network demonstrated a more diversified deposit structure to financial centers. Table IV.5 shows evidence that the network path from depositor to deposit takers generally became longer. In 1859, the average length of the longest shortest path starting from a country bank was 1.1. By 1862, the length of shortest path increased for country banks, indicating a more decentralized network structure, growing from 1.1 to 3. However after the

Table IV.5. Longest Shortest Path and Centrality by Location

	Longest Shortest Path			Betweenness Centrality		
Year = 1859	Mean	Max	Min	Mean	Max	Min
New York City	0.0	0	0	0	0	0
Philadelphia	0.7	2	0	0.0003	0.0030	0
Pittsburgh	0.8	3	0	0.0001	0.0005	0
Harrisburg	0.4	1	0	0.0335	0.1667	0
Country banks	1.1	3	0	0.0099	0.5000	0
Year = 1862	Mean	Max	Min	Mean	Max	Min
New York City	0	0	0	0	0	0
Philadelphia	2.4	5	1	0.0035	0.0221	0
Pittsburgh	1.9	4	1	0.0001	0.0004	0
Harrisburg	1.3	4	0	0.0012	0.0004	0
Country banks	3	6	0	0.0004	0.0053	0
Year = 1867	Mean	Max	Min	Mean	Max	Min
New York City	0	0	0	0	0	0
Philadelphia	1	1	1	0.0002	0.0015	0
Pittsburgh	1.3	3	1	0.0001	0.0002	0
Harrisburg	2	2	2	0	0	0
Country banks	1.8	3	1	0	0.0001	0

Notes: This table shows the statistics of the longest shortest path 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. From 1859 to 1862, the length of shortest path increased for country banks, indicating a more decentralized network structure. In particular, the maximum of this statistics increased from 3 to 6, showing a increase in diversification among bank deposits. Whereas from 1862 to 1867, the length of shortest path decreased for country banks, indicating a more centralized network structure, though not as dense as prior to the Civil War. In particular, the maximum of this statistics decreased from 6 to 3, confirming the 3-tier bank network structure. Betweenness centrality quantifies the number of times a node acts as a bridge along the shortest path between two other nodes. We see the betweenness centrality decreased through out the sample periods, which confirms that banks grow closer to each other during the entire period.

introduction of National Banking Acts, the path do decrease as bank relationships were nearly entirely linked through reserve cities.

Furthermore, the betweenness centrality measures reported in Table IV.5 supports our diversification observations at financial centers. From 1859 to 1862, betweenness centrality decreased across country banks including Harrisburg, indicating that the network structure became more decentralized for these cities. Where as Philadelphia saw an increase, which confirms that banks over all were concentrating their money to financial centers. We see that this trend persisted post the National Banking Acts as the betweeness centrality continues to decrease suggesting that the act help solidify the network structure that had begun to naturally formed due to the Civil War.

The changes we observe in the networks topology suggests that banks by 1862 had begun to orient their relationships to focus on liquidity security via their connection to banks in location where clearinghouses could help protect deposits. Even banks in Philadelphia, which had a clearinghouse at the time, appear to have desired increased protection and thereby began sending interbank deposits onto New York City banks. Further demonstrating that the pre-Civil War transportation and economic relationships that once linked banks had begun to shift by 1862 out of concerns of panics, rather than solely being driven by the National Banking Acts.

Appendix V: Interbank Deposits Relationships

Banks' major correspondents dramatically shifted as the National Banking Act was enacted. This was due to the slow conversion of state banks to national banks in major cities which could act as reserve agents. As a result many newly chartered national banks were created. This caused many banks at the time to reorganize their correspondent relationships. The following two tables document this reorganization. Table V.1 shows the types of institutions and the numbers of each which we observed over the two years.

Table V.1. Bank Deposit Relationships in 1862, 1867

Year	All Banks	*State*	*Converted National*	*New National*	All Relationships
1862	92	*10*	*82*	*0*	208
1867	180	*13*	*82*	*85*	212

Source: Reports of the Several Banks and Savings Institutions of Pennsylvania, National Bank Examination Reports
Note: The table categorizes the banks by what type of institutional they would stay or become by 1867. As there were only state banks and private banks in 1862 we want provide context the composition of banks changed by state banks converting to national banks and showing how much many new national banks were created over this period.

Most Pennsylvania banks up until the National Banking era had had highly stable relationship with a single correspondent bank (Weber, 2003). We find the enactment of the NBA influenced the continuity of these correspondent relationships; causing banks' correspondents in financial centers to shift drastically. In Table 14 we show banks that adopted national charters chose new correspondents to serve as their reserve agents when the new banking system emerged instead of keeping correspondents. Among the seventy-four state banks that switched to national charters, thirty-seven, or half, changed their correspondents. We can see a similar degree of switching for banks that stayed state bank as well.

Table V.2. Continuity of Bank Relationships

	Correspondent		
Year = 1867	Obs	Same Correspondent	Changed Correspondent
State	10	5	5
Converted National	74	37	37

Notes: This table shows the continuity of correspondent relationships. Because state banks could choose to become national banks, we classify them into two types: state banks that stayed as state banks and state banks that converted to national banks.

Using the dataset for 1867, we study what type of correspondents that were chosen, given that half of banks switched their correspondents. We classify both banks and their correspondents into four groups: state banks that maintained their state charters, newly formed state banks, state banks that adopted national charters, and newly formed national banks. Then, for each bank, we study if their correspondents/reserve agents were state banks, converted national banks, or newly formed national banks. We include a fourth category which is the selection of both types of national bank. Table 15 shows that banks that adopted national charters preferred other banks which adopted national charters as their reserve agents over newly chartered national banks. Where as newly chartered national banks preferred other newly chartered national banks as their reserve agents.

Table V.3. Type of Correspondents Chosen

	Correspondent			
Year = 1867	Obs	Converted National	New National	Both National
State	10	5	0	5
Converted National	74	44	25	5
New State	1	1	0	0
New National	91	20	68	3

Notes: This table shows what type of correspondents that were chosen. We classify both banks into four groups: state banks that maintained their state charters (State), newly formed state banks (New State), state banks that adopted national charters (Converted National), and newly formed national banks (New National). Then, for each correspondent, we study if their correspondents/reserve agents were converted national banks or newly formed national banks. There were no state or new state banks which received deposits. We include a third category which is the selection of both types of national bank (Both National). We find that state banks preferred banks that adopted national charters, adopted national charters preferred other banks which adopted national charters as their reserve agents over newly chartered national banks. Where as newly chartered national banks preferred other newly chartered national banks as their reserve agents.