



ECONOMIC RESEARCH
FEDERAL RESERVE BANK OF ST. LOUIS
WORKING PAPER SERIES

Did the Founding of the Federal Reserve Affect the Vulnerability of the Interbank System to Contagion Risk?

Authors	Mark A. Carlson, and David C. Wheelock
Working Paper Number	2016-012D
Revision Date	February 2018
Citable Link	https://doi.org/10.20955/wp.2016.012
Suggested Citation	Carlson, M.A., Wheelock, D.C., 2018; Did the Founding of the Federal Reserve Affect the Vulnerability of the Interbank System to Contagion Risk?, Federal Reserve Bank of St. Louis Working Paper 2016-012. URL https://doi.org/10.20955/wp.2016.012

Published In	Journal of Money, Credit, and Banking
Publisher Link	https://doi.org/10.1111/jmcb.12520

Federal Reserve Bank of St. Louis, Research Division, P.O. Box 442, St. Louis, MO 63166

The views expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Federal Reserve System, the Board of Governors, or the regional Federal Reserve Banks. Federal Reserve Bank of St. Louis Working Papers are preliminary materials circulated to stimulate discussion and critical comment.

Did the Founding of the Federal Reserve Affect the Vulnerability of the Interbank System to Contagion Risk?

Mark Carlson and David C. Wheelock*

As a result of legal restrictions on branch banking, an extensive interbank system developed in the United States during the nineteenth century to facilitate interregional payments and flows of liquidity and credit. Vast sums moved through the interbank system to meet seasonal and other demands, but the system also transmitted shocks during banking panics. The Federal Reserve was established in 1914 to reduce reliance on the interbank system and to correct other defects that caused banking system instability. Drawing on recent theoretical work on interbank networks, we examine how the Fed's establishment affected the system's resilience to solvency and liquidity shocks and whether those shocks might have been contagious. We find that the interbank system became more resilient to solvency shocks but less resilient to liquidity shocks as banks sharply reduced their liquid assets after the Fed's founding. The industry's response illustrates how the introduction of a lender of last resort can alter private behavior in ways that increase the likelihood that the lender will be needed.

JEL codes: E42, E44, E58, G21, N11, N12, N21, N22

Keywords: Federal Reserve System, contagion, systemic risk, seasonal liquidity demand, interbank networks, banking panics, National Banking system

Draft: February 26, 2018

* Carlson: Board of Governors of the Federal Reserve System (Mark.A.Carlson@frb.gov). Wheelock: Federal Reserve Bank of St. Louis (David.C.Wheelock@stls.frb.org). We thank Jennifer Dlugosz, Gary Gorton, Christoffer Koch, Kris Mitchener, Goetz von Peter, Gary Richardson, Carolyn Sissoko, and three anonymous referees for valuable comments, and Peter McCrory and Paul Morris for excellent research assistance. The views expressed in this paper are solely those of the authors and do not necessarily reflect official positions of the Federal Reserve Bank of St. Louis, the Board of Governors of the Federal Reserve System, or their staffs.

The financial crisis of 2007-08 focused renewed attention on contagion risk in interbank networks and the effects of network structure and lender of last resort policies on such risk. This paper examines how the establishment of the Federal Reserve System in 1914 affected contagion risk in the U.S. interbank network for insights about how network structure and the introduction of a lender of last resort can affect the sources and extent of contagion risk in interbank networks. At the beginning of the twentieth century, the United States had an extensive interbank system that performed the clearing of payments and transferred money and capital from regions and sectors with surplus funds to those with deficits, all without the backstop of a central bank. Due to legal restrictions on branching, the U.S. banking system consisted mainly of small, single office banks, with business relationships between banks enabling the system to function. The interbank system had a core-periphery structure. To facilitate interregional payments, invest surplus funds, and to borrow funds when needed, banks throughout the country held substantial deposits with banks in larger cities, which comprised the interbank system's regional nodes, or with leading banks in the system's core cities, especially New York City.

Contemporaries viewed the interbank system as inherently fragile, though necessary for the interregional movement of funds and operation of the payments system. Seasonal pressures routinely strained the system as banks were called upon to provide cash and loans to facilitate the harvesting and marketing of agricultural commodities, for example, and to make payments across long distances (Kemmerer 1910). Banks in agricultural and other regions with seasonal demands relied on correspondent banks for additional funds to meet local needs, but a relatively fixed supply of funds in the aggregate—which contemporaries referred to as an “inelastic currency”—meant that interest rates spiked and credit was tight in peak-demand seasons.

Contemporaries also blamed the interbank system for transmitting shocks through the banking system. The interbank network made the banking system more resilient to isolated liquidity disturbances by allowing those mild shocks to dissipate over the wider banking system. However, interconnectedness meant that local or regional banking panics could become national in scope. Strains on the system became acute when shocks drove up liquidity demand throughout the country, as in the panics of 1893 and 1907 (Calomiris and Gorton 1991; Wicker 2000). In panics, interbank networks transmitted shocks across the system but focused pressures on banks at the center of the network; there banks from throughout the country withdrew funds simultaneously, rather than at the staggered times that characterized ordinary seasonal flows. Faced with considerably larger demand than usual, banks in New York City and other major cities would suspend cash withdrawals, which in turn caused banks in the rest of the country to suspend when they could not obtain funds from their city correspondents.

Reform proponents viewed banking panics as having large economic costs (e.g., Sprague 1908; Kemmerer 1910). The Federal Reserve (Fed) was established expressly to prevent panics and their economic fallout (Owen 1919). To accomplish that objective, the Fed's founders sought to

reduce the importance of interbank linkages, and in particular the role of the New York City banks at the center of the interbank network, while at the same time alleviating money market pressures caused by seasonal and other fluctuations in the demands for money and credit. A system of quasi-public Reserve Banks was set up to supplant the private network of interbank relationships that had both been the conduit for transmitting crises throughout the country and failed to fully alleviate seasonal pressures.¹

This paper examines how the founding of the Fed affected the size of the interbank system and its vulnerability to liquidity and solvency shocks. Traditionally, the Fed has been seen as providing an elastic currency and mitigating seasonal pressures, but otherwise not greatly changing the structure of the banking system, which continued to consist largely of small, single-office banks. By contrast, we argue that the Fed's establishment profoundly affected how banks interacted with each other. We show that the Fed's founding was followed by large reductions in the average volume of interbank deposits (relative to total national bank assets or liabilities) and their seasonal volatility. In part, the decline in the level of interbank balances reflected a shift of required reserve balances from private correspondent banks to the Reserve Banks. More importantly, the Fed's comparative advantage in meeting the seasonal demands for currency and bank reserves, and in providing interregional payments services, meant that national banks had less economic incentive to hold correspondent balances. The reduced volume of interbank deposits as a share of the total assets and liabilities of the national banking system, as well as reduced seasonal pressures on the system, in turn affected the extent to which the interbank system was vulnerable to contagion risk. Whereas several studies have compared the prevalence and characteristics of the banking panics of the 1930s with those of the National Banking era, most focus on the Fed's performance as lender of last resort in comparison with the actions of private bank clearinghouses in the National Banking era (e.g., Friedman and Schwartz 1963; Gorton 1985; Calomiris and Gorton 1991).² However, the interbank system was an important conduit for the transmission of shocks across the banking system in the National Banking era and likely also during the Great Depression (e.g., Mitchener and Richardson 2014). Thus, research on how the founding of the Federal Reserve affected contagion risk in the interbank system enhances our understanding of both the banking panics of the Great Depression and the impact of institutional changes—especially to the lender of last resort—on the vulnerability of interbank systems to contagion risk in general.

¹ Lowenstein (2015) explains how the Fed's decentralized structure reflected populist antipathy toward a central bank dominated by either Wall Street bankers or federal government officials. Jaremski and Wheelock (2016) show that the locations chosen for Federal Reserve Bank offices and Fed district borders reflected the preferences of national banks, which in turn reflected pre-existing interbank connections. Hence, the System was laid over top of the existing interbank network.

² The National Banking era refers to the portion of the nineteenth and early twentieth centuries between the National Bank Acts of the 1860s, which introduced a federal banking charter, and the establishment of the Federal Reserve System in 1914.

Drawing on theoretical descriptions of the functioning of interbank networks and their implications for the stability of banking systems, we construct quantitative measures of the resilience of the interbank system to solvency and liquidity shocks to gauge the impact of the Fed's founding on contagion risk in the interbank system. The insights from theoretical studies suggest that the vulnerability of interbank networks to contagion risk is related both to the extent of interconnections between members of the network and their relative sizes, as well as to the magnitude of shocks hitting the system. Prominent in this literature is the idea that greater interconnectedness can make networks "robust-yet-fragile" (see, for example, Allen and Gale 2007; Gai, Haldane and Kapadia 2011; and Acemoglu, Ozdaglar, and Tahbaz-Salehi 2015). Specifically, greater interconnectedness makes an interbank network more resilient to relatively minor shocks, but can facilitate contagion and be destabilizing if adverse shocks are sufficiently large to eliminate the excess liquidity of the banking system. This may be especially true for core-periphery systems like the interbank system of the National Banking era, where shocks that affect the core are particularly problematic (Glasserman and Young 2015; Capponi and Chen 2015). Consistent with this description, the National Banking era system generally managed seasonal shocks well but broke down during banking panics. Other theoretical papers have considered how the existence of networks can affect bank behavior in ways that impact financial stability. For example, Castiglionesi, Feriozzi, and Lorenzoni (2012) present a model in which interbank markets allow banks to smooth idiosyncratic liquidity shocks and thus hold less cash and lend more than they could without interbank connections. However, lower cash balances imply that aggregate liquidity shocks result in more severe crises. This description also seems broadly consistent with the performance of the interbank system of the National Banking era.

We first examine how the Fed's founding affected solvency risk related to contagion transmitted from central reserve city banks in New York City and Chicago to reserve city and country national banks elsewhere. Drawing on measures inspired by models of contagion in networks, such as Glasserman and Young (2015), we show that contagion risk declined after the Fed was established, reflecting importantly a decline in interconnectedness among national banks.

Next, we consider how the Fed's founding affected the banking system's resilience to liquidity stresses. Liquidity shocks differ from solvency shocks in their effects on bank balance sheets and channels by which they propagate through the interbank system. Again drawing on insights from network literature, we perform "stress tests" to estimate the vulnerability of the national banking system at different points in time to a liquidity shock calibrated to match the Panic of 1893, which was one of the most severe liquidity shocks of the National Banking era. Following the Fed's establishment, national banks held a smaller share of their assets in the form of cash and other liquid assets, suggesting that they expected the Fed to provide liquidity through the rediscounting of commercial paper. Consequently, national banks were *potentially* more vulnerable to contagious liquidity shocks like the Panic of 1893 after the Fed was established despite being less interconnected with each other. This greater vulnerability to the sorts of liquidity shocks that called for a lender of

last resort response illustrates how the introduction of a safety net can alter private behavior in ways that increase the likelihood that the safety net will be needed.

The remainder of the paper is organized as follows: Section 2 examines the extent of interbank connectedness and the effect of seasonal pressures before and after the introduction of the Federal Reserve System. Section 3 discusses how banking panics were transmitted through the interbank system during the National Banking era. Section 4 focuses on how the Fed's founding affected contagion risk among national banks and presents quantitative estimates of the vulnerability of the interbank system to solvency and liquidity shocks. Section 5 concludes.

2. Regulation, Seasonal Demands and the Interbank Network

2.1 Role of the interbank system and interbank balances

In the late 1800s, the U.S. banking system consisted of a large number of small, widely dispersed unit banks. However, commerce was increasingly nationwide in scope, facilitated by improvements in communications and transportation. In this environment, the banking system was required to move funds around the country which, given unit banking, meant that individual banks had to connect with each other through the interbank system. Rather than a complicated series of bilateral flows, transfers of funds between regions were typically routed through leading banks in New York City, Chicago, and other major cities (James 1978; James and Weiman 2010).³

The interbank system was especially important for managing substantial seasonal fluctuations in economic activity associated with agriculture and other commercial activity (Barsky and Miron 1989; Davis, Hanes, and Rhode 2009). The planting, harvesting, distribution and processing of agricultural crops generated large demands for money and credit in spring and autumn months (Kemmerer 1910). Banks in the interior met heightened demands for money by drawing down deposits they held with correspondent banks in the central money markets, which in turn drew funds from banks in regions with less agricultural demand.

Besides their usefulness for making payments and managing seasonal fluctuations in money and credit demands, correspondent balances enabled banks to diversify their asset portfolios and satisfy legal reserve requirements. Banks typically earned 2 percent interest on their correspondent balances, and they could invest a portion of those balances in money market instruments (James 1978). Banks deposited excess funds with correspondents when the funds were not needed locally, and drew down their balances when they needed funds at home. Many banks also borrowed funds from their correspondents, and because loans were typically limited to no more than four or five times

³ James and Weiman (2010) argue that widespread use of checks for making interregional payments depended on the development of a tiered, hub and spoke, national correspondent banking system centered on New York City. Chang, Danilevsky, Evans, and Garcia-Swartz (2008) examine the check-clearing operations of a bank in Bloomington, Illinois in 1910 and find that processing operations were fairly efficient, with correspondent banks in nearby regional centers used for local clearing and banks in New York City used to clear interregional checks.

their average deposit, banks had an extra incentive to hold balances with correspondents (Conway and Patterson 1914).

The structure of legal reserve requirements provided yet another reason for national banks to hold balances with correspondents. National banks in designated central reserve cities (New York City, Chicago and St. Louis) were required to maintain reserves equal to 25 percent of their deposit liabilities, all in the form of gold or other “lawful money.”⁴ Banks located in designated reserve cities were also required to hold reserves equal to 25 percent of their deposits, but half could be held as deposits in national banks in central reserve cities. Finally, national banks in all other cities and towns, referred to as “country banks,” were required to hold reserves equal to 15 percent of their deposits, of which three-fifths could be held as balances in either reserve city or central reserve city national banks. Because banks usually earned interest on their correspondent balances, and because they were useful for making payments and managing seasonal flows, most national banks held a high percentage of their required reserves in the form of correspondent deposits, rather than as vault cash.

The incentives for banks to hold balances with correspondents encouraged interbank deposits to concentrate in major cities, especially New York City and Chicago. The result was a hierarchically-structured interbank system with a small number of very well connected banks at the top that resembled the structure of many modern banking systems, including those of Germany (Craig and von Peter 2014) and the United Kingdom (Gai, Haldane, and Kapadia 2011).

2.2 The Federal Reserve and its impact on the interbank system

Although the interbank system facilitated interregional flows of cash and payments, it did not create additional liquidity. Consequently, interest rates exhibited wide seasonal fluctuations and “seasonal stringency” plagued money markets in autumn months. Kemmerer (1910), Sprague (1913) and other contemporary writers noted that banking panics often occurred at times of the year when the surplus liquidity of the banking system was normally low, and viewed the disruptions caused by panics, including declines in lending and suspensions of cash withdrawals, as having significant macroeconomic consequences.⁵ The major Panics of 1893 and 1907, as well as several other panics of lesser magnitude, prompted calls for reform that led ultimately to the establishment of the Federal Reserve System in 1914.

Reform proponents blamed the nation’s “inelastic currency” for both seasonal stringency and banking panics. They also worried about the resiliency of the interbank market, which was vulnerable

⁴ The National Banking Acts defined lawful money as legal tender notes, gold and silver coin, and Treasury notes (Coffin 1896). Reserves were required against all individual deposits plus net interbank deposits (i.e., deposits due to banks minus deposits due from banks). In the early part of the National Banking era, banks also were required to maintain reserves against their note issues, but that requirement was discontinued in 1874.

⁵ By disrupting normal methods of clearing and settling payments, banking panics and suspensions made long-distance transactions more difficult, which depressed economic activity. By authorizing Federal Reserve to clear and settle payments, the Fed’s founders sought to lower the risk that a panic would impair the payment system. Sprague (1908, 1913) provides a contemporary discussion; James, McAndrews, and Weiman (2012) provide a modern, more formal analysis.

to disruptions caused by panics in the central money markets or elsewhere (Wicker 2000). Indeed, the possibility that money center banks would suspend payments made the interbank system vulnerable to self-fulfilling runs (Vanderlip 1908; Carlson 2015). Reformers recognized that to the extent panics were driven by runs of banks on other banks, then stopping this dynamic was key to ending panics entirely (e.g., Warburg 1916).

Some reformers also decried the concentration of the nation's bank reserves in reserve cities and central reserve cities, especially in New York City, and the investment of surplus funds in the stock market via short term call market loans. Reform proponents sought to distribute the nation's bank reserves more evenly throughout the nation and to break the links between the banking system and the stock market, which were widely viewed as a source of instability.⁶

To solve the problems stemming from ordinary seasonal fluctuations in money and credit demand as well as the acute shortages of liquidity brought about by financial disturbances, reformers sought more flexible supplies of currency and bank reserves. The Aldrich-Vreeland Act of 1908 provided one mechanism for expanding liquidity in a crisis by enabling both individual and groups of national banks to issue currency on an emergency basis against their holdings of commercial paper or government bonds. Emergency currency was issued one time, apparently successfully preventing a panic in the face of large-scale bank runs at the start of World War I (Friedman and Schwartz 1963; Silber 2007).⁷ The emergency currency provisions of the Aldrich-Vreeland Act were intended to be temporary, however, while a National Monetary Commission conducted a thorough analysis of the defects of the U.S. banking and currency system. Although extended for one year under the Federal Reserve Act of 1913, Congress viewed the Aldrich-Vreeland Act's emergency currency provisions as unnecessary once the Federal Reserve System was established, and accordingly let them expire in 1915.

The Federal Reserve discount window was viewed as a more permanent solution to the inelastic currency problem. The System's member banks could obtain currency (Federal Reserve notes) or reserve deposits by rediscounting eligible bank loans at the discount window. Congress limited Fed lending to the rediscounting of short-term commercial and agricultural loans in an effort to make the monetary and banking systems less vulnerable to stock market declines and other financial disturbances.

Congress also sought to lessen the concentration of the nation's bank reserves in New York City and the need for an interbank market to redistribute funds from surplus to deficit regions. To accomplish that objective, the Federal Reserve Act established a system of regional Reserve Banks to hold the reserve deposits of their local member banks and to furnishing them with currency and

⁶ The "Money Trust" investigation by the House Committee on Banking and Currency in 1912-13 exemplified this concern (United States Congress 1912-13).

⁷ Bernstein, Hughson, and Weidenmier (2010) find evidence that the Aldrich-Vreeland Act also helped ease seasonal pressures, possibly because it had the potential to provide liquidity support if the pressures became too large.

additional reserves as needed to accommodate local demands. Rather than having to draw down a deposit or borrow from a New York City (or other money center) correspondent, a Fed member bank could obtain funds from the discount window of its local Reserve Bank. Further, the act specified that only deposits with Federal Reserve Banks or vault cash satisfied a Fed member bank's reserve requirement.⁸ All national banks were required to join the Federal Reserve System, and hence they could no longer satisfy a portion of their reserve requirement by holding balances with reserve city or central reserve city banks.⁹ Finally, the Fed offered check clearing and settlement services for its member banks, and provided a means of interregional settlement. All of these reforms were designed to provide funds locally and facilitate interregional payments, and thereby reduce if not eliminate the need for a private interbank system to distribute funds across the country.

2.3 The size of interbank exposures before and after the founding of the Federal Reserve

The size of the interbank system, measured in terms of the volume of interbank deposits, declined sharply after the Federal Reserve was established. Table 1 reports average volumes of interbank balances held by each tier of national banks during the 20 years of the National Banking era before the Federal Reserve was established (1894-1914) and throughout most of the 1920s (1921-28).¹⁰ The first period begins after the Panic of 1893 and ends with the final report prior to the opening of the Federal Reserve Banks in November 1914. The second period begins in 1921 to avoid the effects of World War I and the immediate post-war period on Federal Reserve and member bank balance sheets.¹¹ The second period ends in June 1928 because thereafter available information on national bank balance sheets do not distinguish between deposits due from national banks and deposits due from state banks. The averages reported in Table 1 for country national banks are based on state-level data, whereas those for reserve city banks are city-level data for national banks in 18 cities that were designated as reserve cities throughout the period.¹² Finally, the ratios for central

⁸ A 1917 amendment eliminated vault cash as a form in which member banks could hold their required reserves.

⁹ Membership in the Federal Reserve System was optional for state-chartered banks. Few state-chartered banks joined the System at first, however, because regulations imposed on member banks were generally heavier than those imposed on most state non-Fed member banks. See Calomiris et al. (2018).

¹⁰ The data are from *Annual Reports of the Comptroller of the Currency* (Office of the Comptroller of the Currency, various), which report balance sheet information for national banks aggregated at the state level for country banks and city level for reserve city and central reserve city banks on designated call dates, which occurred five times per year during 1894-1914 (though not always on the same dates in each year) and three to five times per year during 1921-28. We thank the Federal Reserve Bank of Minneapolis for making the data for 1890-1910 available online (<http://cdm16030.contentdm.oclc.org/cdm/landingpage/collection/p16030coll4>).

¹¹ The Federal Reserve set low discount rates on loans secured by U.S. government bonds while the United States was an active participant in the war and for several months afterward. Banks consequently borrowed heavily from the Fed and held large cash balances. Fed discount rates were raised in 1920-21, and borrowing and reserve balances fell precipitously. By 1922, discount window lending and bank balance sheets displayed regular seasonal patterns and levels. Hence, we focus on the period 1921-28 to assess the long-run impact of the Fed. We also exclude the period from November 1914 to 1918 because national banks were given three years from the opening of the Reserve Banks to comply with the new structure of reserve requirements specified in the Federal Reserve Act and because national bank balance sheet information was not reported consistently throughout the period.

¹² The 18 cities are: Albany, NY; Baltimore, MD; Boston, MA; Cincinnati, OH; Cleveland, OH; Detroit, MI; Kansas City, MO; Louisville, KY; Milwaukee, WI; Minneapolis, MN; New Orleans, LA; Omaha, NE;

reserve city banks are based on city-level data for the three cities designated as central reserve cities during the National Banking era (New York City, Chicago and St. Louis).¹³

Country banks held substantial deposits with correspondents to meet statutory reserve requirements and for the other benefits they provided. Deposits due from national banks averaged 13.8 percent of total country bank assets during 1894-1914, but just 6.8 percent during 1921-28. Reserve city banks also held substantial balances with correspondents. Deposits due from national banks comprised some 16.1 percent of total reserve city bank assets on average during 1894-1914, but just 5.2 percent during 1921-28. Because many reserve city banks were correspondents of country and other banks, they also had large amounts of deposits *due to* respondent banks. Shown on the third line of Table 1, relative to total reserve city bank assets, in the 1920s, deposits due to respondents were about half the volume they had been during 1894-1914.¹⁴ As the central nodes of the interbank system, central reserve city banks had even larger amounts of deposits due to respondents. Reported on the fourth line of Table 1, the deposits of central reserve city banks due to other national banks declined from an average of 24.1 percent of the size of total central reserve city bank assets during 1894-1914 to just 9.4 percent during the 1920s. Note that the differences between the averages for 1894-1914 and the 1920s shown in Table 1 are all statistically significant as well as large. Overall the declines in these ratios indicate that, in terms of interbank deposits, the size of the national interbank system during the 1920s was about half of what it had been during the 20 years before the Federal Reserve was established.

Besides being smaller, the interbank system was also less concentrated in the central reserve cities during the 1920s than before 1914. Shown in the fifth line of Table 1, as a share of all interbank balances in the three central reserve cities and 18 reserve cities, the balances held in the three central reserve cities fell from 64.6 percent during 1894-1914 to 58.7 percent in the 1920s. While the decline was modest, though statistically significant, it is striking given that central reserve city banks held a larger share of the total combined assets of the reserve city and central reserve city banks in the 1920s (56.6 percent) than during 1894-1914 (53.5 percent).

2.4 Seasonal patterns before and after the Fed

Seasonal fluctuations in credit and money demands were important drivers of flows of correspondent deposits through the interbank system. For many country banks, especially in agricultural regions, seasonal peaks in loan demand and deposit withdrawals coincided, which banks

Philadelphia, PA; Pittsburgh, PA; Saint Joseph, MO; Saint Paul, MN; San Francisco, CA; and Washington, DC. Although other cities were later designated as reserve cities, we restrict our sample to these 18 reserve cities for comparability across time.

¹³ For comparability across time, we treat St. Louis as a central reserve city throughout the 1920s even though it was re-designated as a reserve city in 1922.

¹⁴ Respondent banks are the banks that maintain deposits in a given correspondent bank. Those deposits are assets of the respondents and liabilities of the correspondent.

typically met by drawing down their deposits with or borrowing from their city correspondents.¹⁵ Facing demands from their respondents, the city banks would either have to accept a decline in their total liabilities or attract funds from other banks in less agricultural areas (or both).

We examine principal components of intra-year changes in interbank balances for each bank class for evidence on the importance of seasonal pressures on the interbank system over time. For country banks, we calculate the principal components of changes in balances due from national banks (divided by total assets) between call report dates across the 48 states. For reserve city banks, we calculate the principal components of changes in *net* balances due from national banks (i.e., balances due from banks minus balances due to banks, divided by total assets) across the consistent set of 18 reserve cities. Finally, for central reserve cities, we calculate the principal components of changes in balances due to national banks (divided by total assets) across the three central reserve cities. We pool the years 1894-1914 and 1921-28 to observe how patterns change after the Fed was established.

The top panel of Figure 1 plots the first principal component of changes in deposits due from national banks (scaled by total assets) for country banks. This principal component explains 27 percent of the variation across the 48 states, indicating that it importantly reflects nationwide trends in interbank balances. The principal component exhibits a highly seasonal pattern during 1894-1914. The amplitude of the seasonal pattern is decidedly smaller in the 1920s. The standard deviation of the first principal component is 0.12 for 1894-1914, but just 0.04 for 1921-28. Although differences in the frequency of call reports between the two periods preclude formal statistical testing for changes in seasonal patterns, interbank deposit flows appear decidedly less seasonal in the 1920s than they had been before 1914.

The principal component analysis also sheds light on regional differences in the timing of seasonal flows of liquidity through the interbank system. About as many states load positively on the first principal component (25) as load negatively (23), implying that while balances due from national banks were increasing at country banks in some states they were declining in others.

Many of the states that load positively and most heavily on the first principal component of balances due from national banks were heavily involved in cotton production (Alabama, Arkansas, Georgia, Louisiana, Mississippi, South Carolina, Tennessee, and Texas).¹⁶ By contrast, states with negative loadings were mainly in the West and New England, where agriculture was a smaller component of economic activity. For 1894-1914, the correlation between changes in balances due

¹⁵ Banks could of course adjust other balance sheet items, such as their cash reserves. We also recognize that bank balance sheets are at least partly endogenously determined. However, we are more concerned with the correlation in broad balance sheet aggregates across states which are not likely to be affected by the adjustments in these other items or by the endogeneity issues.

¹⁶ The links between regional crop patterns and the principal components fits with historical narratives. For example, the first principal component of due from national banks, which we link to cotton and the southern states, declines one call report after the second principal component. This pattern matches the description of Kemmerer (1910), who reports that flows of funds from New York to southern states peaked later than flows to states in the Midwest (see, e.g., Kemmerer 1910, Chart XXXIII).

from banks (scaled by total assets) in southern states and states in the West and New England is -0.21 . Figure 2 shows a portion of this time series (abbreviated for visual ease). These offsetting flows reflect the movement of funds through the interbank system and illustrate the importance of the interbank system in moving liquidity between regions. In the 1920s, changes in deposits due from banks for the same sets of states are strongly positively correlated ($+0.75$), which is further evidence that the interbank system was less important for meeting seasonal pressures after the Fed was established.

For reserve city banks, shown in the middle panel of Figure 1, the first principal component of changes in net balances due from banks does not show an obvious seasonal pattern. However, because reserve city banks could meet seasonal demands by drawing down their own balances at national banks, it is not obvious that net flows should be seasonal; indeed the lack of an obvious seasonal pattern might indicate that these banks simply passed any pressures from seasonal withdrawals by their respondents on to the central reserve city banks.

The bottom panel of Figure 1 plots the first principal component of changes in deposits due to national banks (scaled by total assets) for the three central reserve cities. This principal component explains 71 percent of the variation over time in changes in balances due to national banks across these three cities. While greater explanatory power is expected because of the smaller cross sectional sample size, it nevertheless points to an important common driver of interbank balances at banks in these cities. A seasonal pattern during the National Banking era is apparent, although there are sharp movements in this principal component at other times as well. The seasonal pattern might be present for a few years in the early 1920s, but is certainly gone by the end of the decade. The volatility of the series is also lower in the 1920s, with the standard deviation of the first principal component falling from .04 in the National Banking era to .02 in the 1920s.

The Federal Reserve Banks contributed directly to reducing seasonal pressures on interbank markets by allowing their own balance sheets to expand and contract seasonally. Federal Reserve credit, particularly discount window loans and Fed purchases of bankers acceptances, tended to rise during months when previously banks had withdrawn funds from correspondents to meet seasonal demands for cash and loans, and when money market conditions had tightened, and fell during months when previously banks had deposited funds with correspondents as local demands eased.¹⁷ In the case of discount window lending, each Reserve Bank set a discount rate and lent currency or reserves at that rate against acceptable collateral. Similarly, each Reserve Bank set a schedule of “bill buying” rates at which it would buy bankers acceptances. The Reserve Banks generally did not make

¹⁷ Data on Federal Reserve credit are available at monthly (and weekly) frequency, but not on most call report dates. Further, the data are aggregated by Federal Reserve districts, rather than at the city or state levels. Although these features of the data make it difficult to show conclusively that Federal Reserve lending was responsible for the substantial reduction in seasonal flows of interbank deposits, Miron (1986) and Wheelock (1992) show that seasonal patterns in Federal Reserve credit match the seasonal patterns in interest rates that existed before 1914.

seasonal adjustments to either their lending rates or terms. Thus, seasonal fluctuations in Reserve Bank lending and acceptance purchases were driven mainly by market demand for liquidity, rather than by explicit supply adjustments by the Fed (Wheelock 1992).

We estimate the seasonal patterns of discount window lending and acceptance purchases by regressing the sum of discount window loans outstanding and Fed holdings of bankers acceptances (“Federal Reserve credit”) on 12 monthly dummy variables, a national index of industrial production (measured relative to January 1915) to capture the effects of the business cycle on the demand for Fed credit, and a time trend. We estimate the model using data for January 1922-August 1931.¹⁸ As shown in Table 2, the coefficients on the monthly dummies indicate strong seasonal patterns with the coefficients for August-December noticeably larger than those for January-July. On average, the Federal Reserve supplied \$350 million more liquidity to member banks via discount window loans and acceptance purchases in December than in April (the typical seasonal low point).¹⁹

Overall, the evidence in this section indicates that flows of interbank balances of national banks were less seasonal in the 1920s than they had been before the Fed was established. Further, the seasonal pattern of Federal Reserve credit suggests strongly that at least some of those seasonal fluctuations were eliminated by the new central bank, as the System’s founders had intended. By varying Federal Reserve credit to meet seasonal fluctuations in money and credit demands, the Fed eliminated one of the economic rationales for interbank connections that had prevailed in the National Banking era as well as the recurring seasonal pressure on the interbank system. The lessening of seasonal flows of interbank balances is also consistent with the well-documented declines in seasonal interest rate and stock return volatilities after the Fed’s founding (Friedman and Schwartz 1963; Miron 1986; Bernstein, Hughson, and Weidenmier 2010).²⁰

3. Banking Panics and Interbank Activity

Banking panics of the National Banking era were characterized by widespread increases in liquidity demand in which normal seasonal patterns and flows broke down. To illustrate the increased

¹⁸ We begin the estimation period in 1922 to avoid a large bulge in discount loans during World War I that resulted from the Fed’s setting of a preferential discount rate for loans secured by U.S. Government securities. Discount loan volume declined sharply in 1921 after the Fed ended the preferential rate and increased the discount rate to a high level. Similarly, we end our estimation period with August 1931 to avoid a sharp and unusual increase in discount window loans during a banking crisis that began after Great Britain left the gold standard in September 1931. We obtain qualitatively similar estimates of the seasonal patterns in Federal Reserve credit if we begin the estimation period prior to 1922 or terminate the period before August 1931, but specific monthly coefficients are somewhat sensitive to the estimation period. Estimation results for other periods are available from the authors upon request.

¹⁹ Seasonal patterns varied somewhat across the Federal Reserve districts. Discount window loans and acceptance purchases of the Boston, New York, Philadelphia, Cleveland and Chicago Reserve Banks typically peaked in December, whereas those of most other Banks peaked in the autumn (September, October, or November). These differences likely reflected the relative importance of financial services and manufacturing in the Northeast and of agriculture in most other regions of the country. Estimation results by Federal Reserve district are available from the authors upon request.

²⁰ See Carlson and Wheelock (2016) for additional discussion of the seasonal patterns of balance sheets of banks in this period.

demand for liquidity and withdrawals of reserve balances during panics, we compare changes in correspondent deposits for all country national banks during the panics of 1893 and 1907 with the average changes during the same months in non-panic years.

The first panic occurred in the summer of 1893. Shown in first row of Table 3, between May and October 1893, country national banks withdrew deposits from correspondents totaling 2.5 percent of their total assets (average across 48 states). During the same months in non-panic years, country banks added to their balances with correspondents by an average of 0.6 percent of their total assets. Similarly, between August and December 1907, when the Panic of 1907 was at its height, country national banks withdrew funds totaling 1.2 percent of their total assets from correspondents, whereas normally in those months country banks increased their deposits by 0.5 percent of their total assets. A similar pattern is apparent if we scale these flows by the total assets of reserve city and central reserve city banks, rather than by the total assets of country banks (row 7).

The geographic breadth of interbank withdrawals during panic periods is also apparent. Normally, between May and October, country banks in the South withdrew deposits from reserve city and central reserve city banks, but country banks elsewhere added to their deposits (rows 2-6). Between October and December the pattern would reverse, with southern banks rebuilding their correspondent balances while banks in other states withdrew deposits or left them relatively unchanged. During the panics of 1893 and 1907, however, withdrawals were both large and widespread, with banks throughout most of the country attempting to withdraw from their city correspondents simultaneously.

Information reported in the bottom two rows of Table 3 show the impact of panics on reserve city and central reserve city banks. During panics, reserve city and central reserve city banks experienced withdrawals of respondent deposits that were much larger than normal.²¹ In 1907, for example, deposits due to national banks fell by an average of 2.7 percent (relative to total assets) at reserve city banks, whereas typically they would decline by just 0.2 percent. Similarly, deposits due to national banks fell by an average of 2.6 at central reserve city banks, rather than the usual decline of 0.3 percent. Somewhat offsetting the loss of interbank deposits, central reserve city banks actually experienced inflows of deposits from their other customers during the panic. That withdrawal pressures on banks at the core of the interbank system came mainly from other banks is consistent with reports by some bankers that banking panics, especially the Panic of 1907, were more panics of bankers than of ordinary depositors (Vanderlip 1908). It also illustrates how the interbank market figured prominently in the financial instability of the National Banking era.

²¹ The “due to national banks” item of reserve city and central reserve city banks includes deposits not only of country national banks, but also of other reserve city and central reserve city banks. In addition to deposits due to national banks, we also examined the behavior of balances due to state banks and trust companies. These other deposits behave similarly and exhibit much steeper declines during the panics.

The differences in interbank deposit flows between the normal seasonal and abnormal panic periods provide an indication of the size of shocks that would shift the system from “robust” to “fragile” in the terminology of Haldane (2009). Ordinarily, offsetting interregional flows meant that seasonal pressures had a relatively modest impact on the total amount of interbank claims in the system. Panics, however, resulted in large declines in total interbank claims which reduced total liquidity in the banking system. The tiered structure of the reserve system amplified these declines. The data reported in Table 3 shows that the declines in interbank claims were not massive. Nevertheless, they were consequential, and a dynamic that we attempt to capture in counterfactual stress tests in Section 4.

4. The impact of the Federal Reserve on contagion risk in the interbank system

Next we examine how contagion risk among national banks changed following the establishment of the Federal Reserve. We consider contagion risk stemming, alternatively, from solvency shocks and from liquidity shocks. A solvency shock impacts the asset side of a bank’s balance sheet and is potentially contagious if the equity of the affected bank is insufficient to absorb losses to the value of the bank’s assets. In that case, the bank is unable to pay off some depositors, which would impair the assets of those claimants. Given the hierarchical structure of interbank claims in the National Banking era network, we consider the potential impact of insolvency of central reserve city banks on the solvency of country and reserve city banks.²² To assess contagion risk from a solvency shock, we employ a theoretically-based measure of the system’s exposure to such shocks from Glasserman and Young (2015).

The dynamics of a liquidity shock were somewhat different. In the case of a liquidity shock, runs by a bank’s depositors might force the bank to liquidate balances it held with correspondents.²³ Again the hierarchical structure of the network suggests a particular path for these withdrawals: deposit withdrawals at country banks force those banks to pull funds (or borrow) from their reserve city correspondents, which in turn liquidate deposits they hold in central reserve city banks. Thus the direction of propagation is the reverse of the solvency shock. To assess contagion risk from a liquidity shock, we use a bottom-up stress-test approach.

4.1 Impact of the Fed on vulnerability to contagion via solvency shocks

We illustrate the potential for the failure of central reserve city banks to impact the solvency of other groups of banks using a measure of contagion risk described by Glasserman and Young (2015). They argue that the impact a set of banks (j) can have on other banks in a network is reflected

²² Gorton and Tallman (2016) document actions by the New York City clearinghouse to assist troubled national banks in the Panic of 1907 and earlier panics. A more recent example that motivates analysis of a top down solvency shock is the rescue of Continental Illinois Bank in 1984. One reason regulators cited for the rescue was that they were concerned that the failure of Continental would have seriously impacted its numerous respondent banks (Federal Deposit Insurance Corporation 1997).

²³ Banks can also experience liquidity shocks if a large number of borrowers simultaneously draw upon lines of credit.

in a contagion index that is a function of i) the size of those banks, ii) their connectedness to the network, and iii) their leverage. Glasserman and Young measure bank size by total net worth; leverage by the ratio of the bank's assets not involving claims on other banks in the financial system to its net worth; and connectedness by the share of a bank's liabilities that are due to other banks in the financial system.²⁴ These items are combined multiplicatively:

$$\text{Contagion index}_j = \text{size}_j * (\text{leverage}_j - 1) * \text{interconnectedness}_j \quad (1)$$

We construct the contagion indexes for the central reserve cities of New York and Chicago.

Following Glasserman and Young (2015), we measure the average resilience of another set of banks (*i*) to shocks to the value of their claims on banks in set (*j*), relative to the resilience of banks (*i*) to shocks to the value of their other assets. This measure is a function of the average size and leverage of banks (*i*):

$$\text{Resilience}_i = \text{harmonic mean of leverage}_i * \text{arithmetic mean of size}_i \quad (2)$$

Greater size (again measured by total net worth) clearly increases the ability of banks (*i*) to withstand shocks directly. Greater leverage, measured by the ratio of assets not involving claims on other banks in the financial system to net worth (as in (1)), implies that the banks in set (*i*) are less likely to be affected by shocks coming from banks in set (*j*) than by losses on their other assets.²⁵

We measure the average resilience of country national banks across the 48 states, and resilience of reserve city banks in the consistent set of 18 reserve cities, on each call report date. We then plot the ratio of the contagion index divided by the average resilience measure over time (specifically, 1894-1914 and 1921-28). Constructing the ratio in this way, the higher the ratio, the more likely that shocks from the central reserve cities will be contagious. A decrease in the ratio implies that that the country banks (or reserve city banks) have become less vulnerable to a shock emanating from the central reserve cities as compared to a direct shock to other assets on their balances sheets. Glasserman and Young (2015) define contagion risk as “weak” if the banks in set (*i*) are more likely to fail from a direct shock to their balance sheets than from contagion; this corresponds to a situation where our ratio is less than 1. The ratio of the contagion index to average resilience is particularly useful in our context in that when the ratio is less than 1 we can be sure that contagion will be weak, regardless of the structure of the rest of the network. In particular, we do not

²⁴ Size can be thought of as the loss absorbing capacity of the set of banks *j*, and hence is measured by net worth. The leverage measure points to assets on which set of banks *j* could experience losses transmitted from the non-financial sector to the financial sector divided by the loss absorbing capacity of the set of banks *j*; losses on financial assets cannot be transmitted to the financial sector because they are by definition already in the financial sector.²⁵ For purposes of this exercise, we treat state-chartered banks as being part of the system. Note that the framework allows banks in set (*i*) to be a subset of other banks in the financial system. This aspect is useful for us because it means that we do not need to know whether the claims that banks in set (*i*) are on banks in set (*j*) or on other banks in the financial system.

²⁵ For purposes of this exercise, we treat state-chartered banks as being part of the system. Note that the framework allows banks in set (*i*) to be a subset of other banks in the financial system. This aspect is useful for us because it means that we do not need to know whether the claims that banks in set (*i*) are on banks in set (*j*) or on other banks in the financial system.

need to know how banks in set (i) are related to each other. In that sense the ratio is also fairly conservative in that it specifies a minimum condition before insolvency due to contagion is possible.

The upper panel of Figure 3 plots ratios of the contagion indexes of New York City banks and Chicago banks to the average resilience of country banks, while the lower panel shows similar ratios for reserve city banks. In general, we find that both country banks and reserve city banks would be strongly affected by a shock emanating from New York, while a shock from Chicago was borderline “weak,” especially for reserve city banks.

It is clear from Figure 3 that, for both country banks and reserve city banks, the likelihood of contagion from either New York banks or Chicago banks was lower in the 1920s than it had been before the founding of the Fed. Table 4 reports average values and standard deviations of the contagion index divided by the resilience measure in the two periods along with the interconnectedness and leverage components. The vulnerability measures are on average some one-third lower in the 1920s than during 1894-1914. The reduction in contagion risk is particularly notable with regard to the vulnerability of country banks to a shock emanating from New York City, but all of the differences are statistically significant.

The decline in contagion risk stemmed mainly from reduced interconnectedness of banks in the central reserve cities. It is important to remember that the vulnerability measure reflects the likelihood that banks in set (i) become insolvent because of defaults by banks in set (j) relative to the risk that banks in (i) become insolvent due to losses on their own loans and other assets. The average leverage of banks in all three groups increased. Greater leverage among country and reserve city banks tended to increase their risk from loan losses or other direct shocks to their balance sheets relative to shocks from central reserve city banks, while increased leverage of central reserve city banks had the opposite effect. Finally, the relative sizes of the three groups of banks changed little over time, but on balance reinforced the effect of reduced interconnectedness in making country and reserve city banks less vulnerable to contagion from central reserve city banks.

4.2 Impact of the Fed on vulnerability to contagion via liquidity shocks

Next we study the impact of liquidity shocks on the national banking system. We do so by constructing a shock that mimics the experience of the banking system during the Panic of 1893. The structure of this shock is in many ways the reverse of the solvency shock considered previously. Here we examine the capacity of the asset-side of bank balance sheets to absorb shocks to the liability-side of the balance sheet.²⁶ The shock is transmitted from the country banks to reserve city and, ultimately,

²⁶ We assume that only liquid assets can be used to meet the shocks. Illiquid assets, such as loans, cannot be sold or liquidated even at fire-sale prices, and we assume that banks are unable to borrow. This is consistent with the ability of banks at this time to suspend withdrawals. It also focuses the exercise more directly on liquidity rather than involving concerns about solvency and the interaction of solvency and liquidity. Banks had some short-term loans, such as overnight loans to the New York call loan market, which could have been liquidated for cash. We would not want to include these among liquid assets in our stress test, however, as our intent is to understand the ability of the banking system to withstand pressures without having to tap outside resources.

central reserve city banks as banks at the lower tiers draw on balances held with banks at higher tiers in the interbank system. In this way, we focus on the importance of linkages between banks as in Allen and Gale (2000); our shocks are also broadly similar to the liquidity shocks in Castiglionesi et al. (2012).

We estimate the stress on the interbank system resulting from a shock calibrated to match the Panic of 1893. The Panic of 1893 originated outside the central money markets and was transmitted via the interbank system to banks in reserve and central reserve cities (Wicker 2000). As with solvency shocks, reduced interconnectedness would tend to make the interbank system more resilient to liquidity shocks. However, because liquid assets generally comprised smaller shares of banks' total assets in the 1920s compared with 1894-1914, the system was potentially more vulnerable to liquidity shocks.

4.2.1 Changes in banks' holdings of liquid assets

Table 5 reports average volumes of liquid assets as a percentage of total assets for each bank class during 1894-1914 and 1921-28.²⁷ Among country banks, liquid assets declined from 20.7 percent of total assets on average before 1914 to 13.6 percent during the 1920s. The declines at reserve city and central reserve city banks were even larger, from 25.6 percent to 12.6 percent for reserve city banks, and from 26.3 percent to 12.0 percent for central reserve city banks. A reduction in reserve requirements might explain some of the decline in average liquid assets ratios. As a percentage of total assets, during the 1920s required reserves averaged less than one half their levels of 1894-1914.²⁸ On average, required reserves were also a smaller percentage of the liquid assets of country and reserve city banks in the 1920s. Figures 4 and 5 show how the group averages of those ratios evolved over time.

Although required reserves were markedly lower in the 1920s and comprised smaller shares of liquid assets for country and reserve city banks, many banks also reduced their buffer stocks of liquid assets, thereby making them potentially more vulnerable to the sorts of liquidity shocks that occurred in the National Banking era. Shown in Table 5, national banks generally held smaller percentages of liquid assets in excess of legal requirements during the 1920s than they had during

²⁷ We define liquid assets as including vault cash and other cash items (bills of other banks, fractional currency, specie, legal tender, United States certificates of deposit for legal tender, and checks on banks in the same place), deposits with national banks (agents and other national banks) and balances with Federal Reserve Banks.

²⁸ The Federal Reserve Act reduced required reserve ratios on net demand deposits to 18 percent for central reserve city banks, 15 percent for reserve city banks and 12 percent for country banks, and established a required reserve ratio of 5 percent for time deposits for all member banks. Required reserve ratios were further reduced in 1917 to 13 percent, 10 percent, and 7 percent for demand deposits, and to 3 percent on time deposits, where they remained throughout the 1920s. (Board of Governors of the Federal Reserve System 1943, Table 107, p. 400). For 1894-1914, required reserves equals the relevant ratio multiplied by the following expression: [individual deposits + U.S. Government deposits + max(0, net deposits due to banks) – clearinghouse exchange and cash items]. See Coffin (1896). For the 1920s, required reserves equals the relevant ratios multiplied by net demand deposits and total time deposits. See Board of Governors (1943, pp. 65-67) for details.

1894-1914.²⁹ That is, even taking account of the reduction in reserve requirements, on average, liquid assets comprised smaller percentages of total bank assets during the 1920s than they had during the 20 years before the founding of the Fed. Moreover, on average banks held little or no reserves in excess of legal requirements in the 1920s. Average ratios of excess reserves to total reserves dropped from 46.5 percent during 1894-1914 to 8.2 percent for country banks, from 25.5 percent to -0.1 percent for reserve city banks, and from 7.0 percent to 0.7 percent for central reserve city banks in Chicago and New York City.³⁰ All of the differences between the two periods are both economically meaningful and statistically significant.

Although the average ratios of liquid assets to total assets were lower in the 1920s for all three classes of national banks, the drop in excess liquid assets at country banks was not as dramatic as those at reserve city or central reserve banks. Moreover, country banks saw some decline in excess liquidity ratios before 1914. Many country banks were located in smaller cities and towns in rural farming areas, and thus more exposed than banks in larger cities to sharply falling agricultural prices and farm incomes, and associated farm bankruptcies and bank failures, that occurred in the early 1920s (Alston 1983; Alston, Grove and Wheelock 1994). In addition, country banks were generally located farther from a Reserve Bank or branch than reserve city and central reserve city banks, which limited their ability to quickly obtain cash or loans from the Federal Reserve (nearly all Federal Reserve offices were located in reserve or central reserve cities). Thus, an increase in liquidity and failure risk associated with the agricultural crisis, coupled with relatively more limited access to Federal Reserve offices, likely explains the relatively modest decline in excess liquid assets at country banks.

By contrast, reserve city and central reserve city banks held decidedly smaller percentages of excess liquid assets in the 1920s than they had before 1914. The decline in excess liquid assets as a percentage of total assets among banks in reserve cities is especially noteworthy because those banks were subject to “two-way” liquidity risk, i.e., risk that withdrawals by their country bank respondents would force them to draw on their own correspondent balances in the central reserve cities. Calomiris and Carlson (2017) find that such risk was a significant problem during the Panic of 1893 when suspensions by central reserve city banks prevented reserve city banks from obtaining funds to satisfy withdrawal requests from their country bank respondents. By reducing demands on the interbank system for liquidity, the Fed’s presence promised to ease the pressures on banks at the central nodes of the interbank system. Those banks responded by adjusting their portfolios toward less liquid loans and investments. For banks to hold less cash in the presence of a central bank capable of providing

²⁹ Excess liquid assets are defined as total liquid assets minus required reserves. Note that total liquid assets consist of assets that satisfy statutory reserve requirements and other liquid assets, e.g., vault cash in the 1920s.

³⁰ We omit St. Louis from this calculation because of the change in its status from central reserve city to reserve city in 1922.

liquidity is perhaps not surprising, but it does mean that the resilience of the system to liquidity shocks might depend on the central bank actually providing additional liquidity if a shock does occur.

Before turning to our stress test, we consider whether the declines in liquid asset percentages were due to the establishment of the Fed. To shed light on this question, we examine the responsiveness of bank liquid asset ratios to Reserve Bank discount rates. Presumably, if the Fed's presence influenced the demand for liquid assets, then banks would be responsive to the discount rates set by the individual Reserve Banks. At various times, Reserve Bank discount rates were not uniform. If banks were sensitive to borrowing costs, we would expect banks in districts with higher discount rates would hold larger buffer stocks of liquid assets to lessen the chance of having to borrow from the Fed. Indeed, we find that during a period when Reserve Bank discount rates differed across districts for a sustained period, 1924-25, the mean liquid asset/total asset ratio of country national banks in states located in districts with a discount rate below the modal rate (Districts 1, 3, 4, and 12) was 0.127 (standard deviation of 0.009) while the mean for banks located in all other states was 0.163 (standard deviation of 0.010). Thus, as expected, on average banks had higher liquid asset ratios in the districts with higher discount rates, suggesting that banks' decisions about their asset portfolios were responsive to the presence of the Fed and its policies in their portfolio decisions.³¹

4.2.2 Changes in the vulnerability of the banking system to liquidity shocks

For our stress test, we view liquidity shocks as reflecting draws on national banks from outside the national banking system—in particular from non-bank depositors (firms, households, and governments) and state-chartered banks. To calibrate the shock, we calculate the percent change in deposits of individuals and state-chartered banks at national banks in each state, reserve city, and central reserve city between May and October 1893. These observed deposit declines understate the true pressures faced by national banks because withdrawals were suspended in some cities. The months of May to October spanned two call report dates. Since the panic covered the entire period, and liabilities lost in the first part of the period were generally not replaced in the second, we define the panic shock as the net outflow of deposits from May to October. We then simulate how an outflow of that size would have affected the national banking system in 1894-1914 and 1921-28. The rate of decline in deposits for national banks in the Panic of 1893 was slightly less than the decline experienced by national banks from June 1931 to June 1932 during the panics of the Great Depression. Hence, the 1893 panic is a historically plausible benchmark for examining how the interbank system's vulnerability to a large liquidity shock evolved over time.

³¹ To further test this hypothesis, we regressed the liquid assets/total assets ratio of national banks on an indicator variable for whether their Reserve Bank's discount rate was below the modal discount rate of all Reserve Banks, and fixed effects for the district and call report date. We estimated the panel regression using state-level data for country national banks for the period from mid-1923 to mid-1927 when Reserve Bank discount rates were not uniform. The model included robust standard errors clustered by states. The estimated coefficient on the discount rate dummy of -0.01 is statistically significant at the 1 percent level and indicates that a 50 basis point reduction in the discount rate would increase the liquid asset ratio by about 1 percentage point, compared with a mean of 13 percent.

We assume that banks use their entire stock of liquid assets, including their required reserves, to meet withdrawals. Both the National Banking Acts and the Federal Reserve Act made clear that a bank's total reserve, including its required reserve, should be used to satisfy deposit withdrawal demands.³² Thus, the relevant measure for determining whether banks had sufficient liquidity to meet deposit withdrawals and avoid suspending in a panic is total liquid assets, rather than liquid assets in excess of required reserves. Moreover, while the ratios of excess liquid assets to required reserves were somewhat higher in the 1920s than in the National Banking era for country and reserve city banks, national banks rarely held any lawful reserves (i.e., deposits with Federal Reserve Banks) in excess of legal requirements. According to Board of Governors (1943, p. 365), "Prior to 1931 aggregate reserve balances corresponded closely to required reserves, and member banks were generally forced to borrow when they lost reserves or their requirements increased." Data reported in Board of Governors (1943, p. 395) show that the excess reserves of member banks were very small, and sometimes negative, throughout the 1920s.

The first step (step 1) of the stress test involves estimating the impact of the 1893 liquidity shock on country national banks at each call report date. We assume that the country banks first meet deposit outflows by running down their cash—specifically the following call report variables: cash items, bills of other banks, fractional currency, specie, and legal tender.³³ For the 1920s, we also include deposits held with the Federal Reserve.³⁴ For the National Banking era, we assume that country banks draw down their balances with reserve agents up to the amount that they reported

³² The Comptroller of the Currency stated that: "The evident theory of the law is that a bank shall always have on hand such an amount of lawful money as will enable it under normal conditions of business to meet the current demands of its depositors. A careful examination of section 5191, United States Revised Statutes, as amended, will show that it is expected that emergencies will arise under which this fund will fall below the legal requirements. This contingency is distinctly recognized by the plain provisions contained in the section named, prescribing what shall be done "whenever the lawful money reserve of any association shall be below the amount of the required percentage of its deposits."...In [this] case, the only safe and prudent course for the bank to pursue is to cease paying out money in any direction *except to depositors* [italics added] until either through the collection of demand or maturing loans on the one hand, or the receipt of deposits on the other, the required proportion has been restored." (*Annual Report of the Comptroller of the Currency*, 1893, p. 18). Similarly, the Federal Reserve Act (Section 19) specified that "The reserve carried by a member bank with a Federal Reserve Bank may, under the regulations and subject to such penalties as may be prescribed by the Federal Reserve Board, be checked against and withdrawn by such member bank for the purpose of meeting existing liabilities: Provided, however, That no bank shall at any time make new loans or shall pay any dividends unless and until the total reserve required by law is fully restored."

³³ Legal tender includes United States certificates of deposit for legal tender notes. During the Panic of 1893, country national banks experienced a decline in deposits of individuals totalling \$190 million out of total initial deposits of \$950 million, and a decline in deposits of state banks totalling \$9 million out of an initial total of \$25 million. To meet these withdrawals, country banks had a total of \$135 million in cash, \$38.5 million in balances at national banks other than reserve agents (although aggregate deposits due from non-reserve-agent national banks minus aggregate deposits due to non-reserve-agent national banks was about zero), and \$121 million in balances at reserve agents in May 1893.

³⁴ In the 1920s we also include checks on banks in the same place and outside checks and cash items. Otherwise, we do not include "float," either in the form of clearinghouse exchange or items with the Federal Reserve in process of collection. Including these as liquid assets does not affect our general conclusions but does have an impact on the quantitative difference between the pre-Fed and post-Fed period as float was substantially higher in the 1920s.

holding with those agents if they do not have sufficient cash to meet withdrawals. Because call reports do not distinguish between balances at reserve city agents and central reserve city agents, we assume that one-third of country bank withdrawals are from central reserve cities and the rest are from reserve cities.³⁵ This assumption affects how shocks are distributed between reserve city banks and central reserve city banks, but not the size of the shock coming from the country banks. Further, we assume that country banks can withdraw balances due from national banks other than reserve agents in states where such balances exceed deposits due to national banks. That is, we allow country banks to draw the difference between balances due from national banks and due to national banks if that difference is positive for a given state. We assume that these withdrawals are from reserve city or central reserve city banks (rather than from other country banks).³⁶

Next (step 2), we consider the impact of the liquidity shock on reserve city banks. We assume the shocks to reserve city banks consist of two parts. The first is a decline in deposits of individuals and state-chartered banks equal to the rate experienced during the Panic of 1893 in the given city multiplied by the current amounts of such liabilities (the same procedure as for the country banks).³⁷ The second part reflects withdrawals by country national banks based on the results from step 1. Because of limitations in the data, we assume that withdrawals by country national banks from a given reserve city equal the decline in deposits due from reserve city agents in all reserve cities multiplied by that reserve city's share of all deposits due to national banks at all reserve city banks. For example, if Boston (a reserve city) had 10 percent of the deposits due to national banks among all reserve cities, then we assume that 10 percent of withdrawals by country national banks from reserve city banks came from banks in Boston. Thus, for each reserve city k out of the set of all reserve cities K :

$$\begin{aligned} \text{withdrawals}_k = & \text{indiv dep}_k * \text{panic \%}\Delta_k + \text{due to state banks}_k * \text{panic \%}\Delta_k + \\ & \Delta \text{ due from agents at country banks} * .67 * \frac{\text{due to national banks}_k}{\sum_k \text{due to national banks}} \end{aligned} \quad (3)$$

As with country banks, we assume that reserve city banks first use cash (defined as before) to meet withdrawals and then withdraw balances due from their own agents in central reserve cities, up

³⁵ Reserve agents were correspondent banks in which country and reserve city banks could hold deposits to satisfy a portion of their reserve requirements. On average, approximately one-third of all country bank balances due from agents during the National Banking era were held in central reserve city banks.

³⁶ This assumption may slightly upwardly bias our estimate of the impact on reserve city banks. However, it will be the same upward bias throughout the sample period. Given shifts in how interbank balances are reported following the establishment of the Fed, this assumption is useful in making the analysis consistent over time. Moreover, we expect any bias to be slight because, if the country banks did withdraw these funds from other country banks, it would simply increase the withdrawal pressures on those institutions which they would in turn pass on to their agent banks in the event that they did not have sufficient cash on hand, as was generally the case.

³⁷ During the Panic of 1893 individual depositors withdrew \$54 million out of total deposits of \$393 million, and state banks withdrew \$8 million out of a total of \$46 million held by national banks in the 18 reserve cities. To meet these withdrawals, reserve city banks (in May 1893) had a total of \$77 million in cash, \$37 million in balances at national banks other than reserve agents, and \$51 million in balances at reserve agents.

to the amount they held with those agents. In the National Banking era, where call reports distinguish between balances due from agent banks and due from other national banks, we assume that the balance sheet item “due from national banks (other than reserve agents)” reflects balances with other reserve city banks; thus, from the point of view of our exercise, withdrawals of these non-agent deposits from one reserve city would be a gain to another reserve city and thus have no net effect on the set of reserve city banks. To the extent that some non-agent deposits were actually held with central reserve city banks, we are understating the pressures on central reserve city banks. For the 1920s, we assume that 65 percent of reserve city deposits with agents were due from banks in central reserve cities, which was the average share of all reserve city bank balances with agent banks in central reserve cities before 1914.³⁸

The number of reserve cities changed over time. We track individually the 18 cities that were reserve cities over the entire period. We pool the remaining reserve cities into a composite “other reserve cities” group and treat this pool as a single reserve city. We assume that this pooled reserve city experiences withdrawals equal to the median experience of the 18 reserve cities.

We can create four metrics based on the results of the exercise so far: the ratio of total withdrawals from reserve city banks relative to their cash; the ratio of total withdrawals from reserve city banks relative to their cash and balances due from agents; the number of reserve cities that exhaust their cash balances; and the number of reserve cities that exhaust their cash and balances due from agents. A ratio that exceeds 100 percent indicates that the reserve city banks collectively did not have sufficient resources (cash or cash plus balances with agents) to meet withdrawal demands.

We next consider the impact on the three central reserve cities (step 3). For consistency, we treat St. Louis as a central reserve city even though it converted to a reserve city in 1922. The procedure here is similar to that used for the reserve cities. We assume that central reserve city banks experienced withdrawals equal to the run off rates from their own individual deposits and balances owed to state banks during the Panic of 1893, declines in deposits due to country banks from step one, and declines in deposits due to reserve city banks from step two.³⁹ We apportion declines in deposits due to country banks and reserve city banks based on the total deposits due to national banks at each central reserve city. Thus, for each central reserve city l of the set of all central reserve cities L , withdrawals are:

$$\begin{aligned} \text{withdrawals}_l &= \text{indiv dep}_l * \text{panic \%}\Delta_l + \text{due to state banks}_l * \text{panic \%}\Delta_l + \\ &\Delta \text{ due from agents at country banks} * .33 * \frac{\text{due to national banks}_l}{\sum_l \text{due to national banks}} + \\ &\Delta \text{ due from agents at reserve city banks} * \frac{\text{due to national banks}_l}{\sum_l \text{due to national banks}} \end{aligned} \quad (4)$$

³⁸ Alternatively, we could assume that all balances are held at central reserve city banks. Doing so has only modest effects on our results, especially once we take into account step 4 below.

³⁹ Individual depositors withdrew \$52 million out of total deposits of \$383 million, and state banks withdrew \$13.5 million out of a total of \$81 million from central reserve city banks during the Panic of 1893. To meet these withdrawals, central reserve city banks had a total of \$134 million in cash on hand in May 1893.

We assume that central reserve city banks can only use cash (including reserve deposits with the Fed) to meet withdrawals. There are no other banks from which they can pull funds. We assume that any balances they hold with other national banks are in other central reserve cities and thus net out for the group as a whole. We assume that central reserve city banks suspend if they do not have sufficient cash to meet withdrawals. We then calculate the ratio of withdrawals to cash available, both at the individual central reserve cities and as a group. If this latter ratio is greater than 100 percent, then the system does not have enough cash to avoid suspension of payments.

As a final step, we account for contagion back to the reserve cities (step 4). Specifically, if the shock to the central reserve cities exceeds their combined cash holdings, we limit the amount that reserve city banks can withdraw from central reserve cities to reflect the degree by which total withdrawal demand exceeds the available cash at central reserve city banks.⁴⁰ This effectively limits the balances due from agents that reserve city banks have available to meet shocks, which could increase the number of reserve cities that exhaust their liquid resources and must suspend.

In conducting this exercise, we make several other assumptions worth noting. First, we assume that balances held at state banks cannot be used as a liquid resource. It seems unlikely that balances with state banks would be available if state banks were themselves drawing down their balances with national banks.⁴¹ Second, we assume that banks cannot borrow from each other (for example by rediscounting loans). The literature (e.g., James 1978, Calomiris and Carlson 2017) suggests that banks usually borrowed from their agents in New York City and Chicago, which would mean that our exercise underestimates the amount of stress being put on the upper tiers of the reserve pyramid. Third, we assume that the liquidity of particular assets remained constant over time. While this is unlikely to have been true over the nearly four decades we consider, there appear to have been changes in both directions. For example, Treasury securities became more liquid as that market deepened (Garbade 2012), while loans, which comprise the largest part of bank balance sheets, generally became less liquid over time as banks extended maturities and shifted away from providing loans against “self-liquidating paper” (Moulton 1918). Thus the net effect is unclear. In addition, many of these trends occurred over relatively long periods, while the shift in liquidity we observe (and report in Table 5) appears to have occurred quickly.

Figures 6-7 present estimates of the size of panic withdrawals as a percentage of liquid assets on each call report date for reserve city banks, and the number of reserve cities where national banks had insufficient liquidity to meet panic withdrawals on each date. As shown in Figure 6, we estimate

⁴⁰ Thus, we assume that reserve city banks can only obtain cash from central reserve city banks up to the lesser of 1) the deposits they have with central reserve city banks or 2) the cash that central reserve city banks have on hand. As a consistency check, we verify that estimated withdrawals by national banks are less than deposits due to national banks for both central reserve city banks and reserve city banks.

⁴¹ For instance, Vanderlip (1908) reports heavy withdrawals by state banks from national banks during the panic of 1907. Calomiris and Gorton (1991) note that the suspension rate of state banks tended to be higher than the suspension rate of national banks; if the state banks were suspended, they would be unable to redeem interbank deposits.

that, throughout the National Banking era, a panic shock on the order of magnitude of the 1893 shock would have depleted the cash resources of the reserve cities as a group (as the ratio of withdrawals to cash holdings always exceeds 100%). However, by drawing down their balances held with reserve agents in central reserve cities, banks in reserve cities usually would have had sufficient resources to avoid suspending (the ratio generally remains below 100%). Interestingly, we find that in the early 1900s, banks generally held less cash relative to the potential run off (as reflected in Figure 6 by an increase in the ratio of panic withdrawals to liquid assets), but after the Panic of 1907 they increased their cash holdings relative to potential withdrawals.⁴² We also find that reserve city banks were more vulnerable to liquidity shocks in the 1920s, reflecting a reduction in their overall holdings of cash and other liquid assets. As shown in Figure 7, we estimate that, throughout the 1920s, a Panic of 1893-size shock would have exceeded the liquid assets of banks in at least 13 and as many as 17 of the 18 reserve cities.

Figures 8 and 9 illustrate the impact of the liquidity shocks on central reserve cities. During the 1890s, we find that, as a group, central reserve city banks had sufficient cash on hand that, had they been willing to deplete it almost entirely, they could have met withdrawals of the size experienced during the Panic of 1893.⁴³ The amount of cash relative to potential withdrawals was lower in the early 1900s, except for a short period following the Panic of 1907. We also observe that central reserve city banks were considerably more vulnerable in the 1920s than they had been in the National Banking era. This heightened vulnerability owes to a decline in their cash holdings (which includes their balances with the Federal Reserve), which more than offset the declines in the deposits that country and reserve city banks held in the central reserve cities.

Table 6 reports sub-period averages for the results shown for reserve city and central reserve city banks in Figures 6 and 8, as well as averages for country banks. For example, for the country banks, we estimate that panic withdrawals would have equaled 195.9 percent of their available cash on average during 1894-1914, and 236.4 percent during 1921-28. Including deposits due from correspondents, we estimate that withdrawals would have totaled some 72.5 percent of country bank liquid assets on average during 1894-1914, and 136.3 percent on average during 1921-28. Thus, among all three classes of national bank, potential vulnerability to a liquidity shock was higher during the 1920s than it had been before 1914.⁴⁴

⁴² The decline in liquidity at city banks in 1906-07 likely stems, at least in part, from gold outflows associated with actions by the Bank of England and other European central banks to attract gold (Odell and Weidenmier 2004).

⁴³ To create the figure, we pool the liquid resources of the central reserve cities. While in many cases, the central reserve city banks may have had sufficient cash in the aggregate, the cash was probably not evenly distributed among the banks. Even though they cooperated under the offices of the clearinghouse, and in a sense merged their balance sheets and issued clearinghouse certificates, they still ended up suspending. See Wicker (2000) for more details about the Panic of 1893.

⁴⁴ In addition to being large, the increases in the mean ratio of withdrawals to liquid assets between 1894-1914 and 1921-28 shown in Table 6 are statistically significant (*p*-value less than .01) for each bank class.

Our results suggest that banks believed that the Fed would be a dependable source of liquidity in a crisis. Clearly, if the Fed did fulfill this promise, then banks did not need to hold as much cash and other liquid assets as before. Although the presence of the Fed seems to have encouraged banks to hold lower proportions of liquid assets, that was not inherently a negative effect from a societal point of view. If banks hold less cash but make more loans then the result might be a net social gain.

Policymakers simply need to be aware of the trade-offs that are incurred. Indeed, the reduction in required reserve ratios shown in Table 5 indicates that policymakers intended some reduction in bank holdings of liquid assets (cash, near cash, due from national banks, and due from the central bank). Warburg (1916) argued that the presence of the Fed reduced the need for banks to hold liquid assets and justified lower reserve requirements. That national banks reduced their liquid asset proportions by more than intended by the reduction in required reserves suggests that the amount of liquidity insurance provided by the Fed was greater than policymakers had anticipated.

5. Conclusion

The Federal Reserve System was designed to overcome the flaws of the U.S. banking and monetary system that reformers believed were the root cause of banking panics. Of course, the design also reflected political compromises and realities. Ending unit banking was not politically feasible; nor was the creation of a truly centralized central bank with unlimited discretion to act as lender of last resort. The Fed's founders responded to their observations about the National Banking system by constructing a system to address the problems of an inelastic currency, seasonal stringency, and dependence on interbank ties that reformers viewed as contributing to an unstable banking system. They observed regional differences in the demands for currency and bank loans, particularly differences associated with the seasonal demands of agriculture and other sectors, and designed a system of self-sufficient regional Reserve Banks to respond to local demands.

After the Fed was established, the banking system appears to have changed in ways that the System's founders had hoped. In particular, the volume of balances that national banks maintained with each other declined, especially the share of those balances held in central reserve city banks. Importantly, this seems to have occurred in part as the underlying economic motivations for the correspondent banking system were addressed. The provision of elastic supplies of currency and bank reserves by the Federal Reserve mitigated the need of banks to draw funds from each other to meet seasonal demands. The Fed also provided payment clearing services previously provided by the money center banks and encouraged banks to use those services.

However, with the creation of the Federal Reserve new incentives also emerged. The presence of a lender of last resort that was capable of providing emergency as well as seasonal liquidity seemingly enabled national banks to rebalance their portfolios toward less liquid loans and securities, and less stable funding sources, such as deposits of state-chartered banks that chose not to join the Federal Reserve System. Non-members lacked direct access to the Fed's discount window and instead had to rely on relationships with member banks for indirect access to liquidity support. Few state-

chartered banks joined the Federal Reserve System because membership required compliance with regulations and supervision that were often more strict than applied to non-member banks, and non-member banks became a more important funding source for some national banks during the 1920s. Both the reduction in liquidity and greater dependence for funding on non-member bank deposits increased the likelihood that shocks would exhaust the liquid asset of member banks and force them to turn to the Fed for assistance. Indeed, Mitchener and Richardson (2014) argue that this dynamic occurred in the Great Depression as withdrawals by non-member banks drained liquidity from member banks and forced a reduction in their lending.

An important lesson that, perhaps, the Fed's founders did not comprehend, or at least that they failed to adequately address, concerned the pressure on the entire banking system that can occur during a crisis. Our study of the behavior of interbank deposit flows of national banks during the Panics of 1893 and 1907 shows that the demands placed on the system during those crises swamped the normal seasonal patterns in which flows of funds out of some regions partly offset flows into other regions. By providing a means by which member banks could obtain additional currency or reserve balances by rediscounting commercial loans with the Federal Reserve Banks, Congress sought to provide an elastic currency. Thus, implicitly, if not explicitly, the Fed's discount window was intended to serve as the lender of last resort for the banking system. However, the Federal Reserve Act placed limits on discount window lending by restricting access to the window to only member banks and by defining narrowly the types of loans that could be used as collateral for discount window loans. During the Depression, bank failures and suspensions were more common among non-Fed-member banks. In addition, some Fed members were unable to borrow because they lacked acceptable collateral (Bordo and Wheelock 2013). The Fed's ability to act as lender of last resort was also constrained, at least potentially, by the gold reserve requirements imposed on the Reserve Banks. Although the Fed could suspend its requirements temporarily (under Section 11(c) of the Federal Reserve Act), in practice the Reserve Banks were reluctant to do so, or even to lend reserves to each other. Finally, the Federal Reserve Act provided the Fed with no specific instructions on how to respond to crises. Some of the Reserve Banks took a broad view of their rights and responsibilities as lenders of last resort, whereas others took a narrow view, for example by strictly enforcing collateral requirements for discount window loans.⁴⁵

Congress responded to the Fed's failure to prevent banking panics or the Great Depression by both relaxing the constraints on the Fed's ability to lend, especially in a crisis, and by reducing the

⁴⁵ The differences in the behavior of different Reserve Banks is illustrated by Richardson and Troost (2009), who compare the performance of banks and the economy in the southern half of Mississippi, which is part of the 6th Federal Reserve District (based in Atlanta) and the northern half of the state, which is part of the 8th District (based in St. Louis). The study finds that the more liberal lending policies of the Federal Reserve Bank of Atlanta enabled banks in the southern half of Mississippi to weather the crises much better than the banks in the northern half of the state, with demonstrably better economic performance resulting in the southern half of the state. Carlson, Mitchener, and Richardson (2011) find that the 6th district was particularly active in its role as a lender of last resort in the late 1920s.

autonomy of the individual Reserve Banks. The Federal Reserve Board (which was renamed the Board of Governors of the Federal Reserve System) was given more explicit authority over Reserve Bank discount rates and policies, and monetary policy was lodged in a reconstituted Federal Open Market Committee with the Board making up a majority of its membership. The reforms made the Fed a more robust lender of last resort, and since the Depression, the Fed has demonstrated a much greater willingness to respond to financial disturbances (Carlson and Wheelock 2015).⁴⁶

Today, national financial markets are becoming increasingly connected. The same financial institutions are major players in many different markets and are increasingly finding it possible to obtain funding in one country while making loans (or providing other financial services) in another. Moreover, over time, international banks have developed additional channels and markets through which they can borrow and lend to each other. Castiglionesi, Feriozzi, and Lorenzoni (2012) cite this increasing connection as motivation for their network model. While this development makes these institutions more resilient to localized shocks, the financial crisis of 2008-09 shows how greater interconnections can also cause funding pressures to spread globally.

The historical experience we describe in this paper illustrates the robust-yet-fragile experience of the core-periphery system. As such, it underscores the importance of a strong liquidity response on the part of the institutions charged with maintaining the liquidity of the core. It also provides a note of caution. Having a mechanism in place to provide liquidity support can encourage banks to act in ways that increase the need for that support. Thus, policies that lean against this moral hazard are also a vital part of the regulatory response.

⁴⁶ Ironically, Congress tightened constraints on Federal Reserve lending after the financial crisis of 2008-09, particularly on the Fed's ability to lend to individual firms under Section 13(3) of the Federal Reserve Act, which had been added during the Great Depression.

References

- Acemoglu, Daron; Ozdaglar, Asuman; and Alireza Tahbaz-Salehi (2015). “Systemic Risk and Stability in Financial Networks,” *American Economic Review*, vol. 105(2), pp. 564-608.
- Allen, Franklin and Douglas Gale (2000). “Financial Contagion,” *Journal of Political Economy*, vol. 108(1), pp. 1-33.
- Allen, Franklin and Douglas Gale (2007). *Understanding Financial Crises*, Oxford: Oxford University Press.
- Alston, Lee J. (1983). “Farm Foreclosures in the United States during the Interwar Period,” *Journal of Economic History* 43, pp. 885-903.
- Alston, Lee J.; Grove, Wayne A.; and David C. Wheelock (1994). “Why Do Banks Fail? Evidence from the 1920s,” *Explorations in Economic History* 31 (4), October, pp. 409-31.
- Barsky, Robert B. and Jeffrey A. Miron (1989). “The Seasonal Cycle and the Business Cycle,” *Journal of Political Economy*, vol. 97(5), pp. 503-34.
- Bernstein, Asaf; Hughson, Eric; and Marc D. Weidenmier (2010). “Identifying the Effects of a Lender of Last Resort on Financial Markets: Lessons from the Founding of the Fed,” *Journal of Financial Economics*, October, vol. 98(1), pp. 40-53.
- Board of Governors of the Federal Reserve System (various). *Federal Reserve Bulletin*. Washington, D.C.
- Bordo, Michael D. and David C. Wheelock (2013). “The Promise and Performance of the Federal Reserve as a Lender of Last Resort 1914-1933.” In Michael D. Bordo and William Roberds, eds., *The Origins, History, and Future of the Federal Reserve: A Return to Jekyll Island*. Cambridge: Cambridge University Press, pp. 59-98.
- Calomiris, Charles W. and Mark Carlson (2017). “Interbank Networks in the National Banking Era: Their Purpose and Their Role in the Panic of 1893,” *Journal of Financial Economics*, 125 (September) pp. 434-453.
- Calomiris, Charles W. and Gary Gorton (1991). “The Origins of Banking Panics: Models, Facts, and Bank Regulation,” in R. Glenn Hubbard, ed., *Financial Markets and Financial Crises*. Chicago, University of Chicago Press, pp. 109-73.
- Calomiris, Charles W.; Jaremski, Matthew; Park, Haelim; and Gary Richardson (2018), “Liquidity Risk, Bank Networks, and the Value of Joining the Federal Reserve System.” *Journal of Money, Credit and Banking*, forthcoming.
- Capponi, Agostino and Peng-Chu Chen (2015), “Systemic Risk Mitigation in Financial Networks,” *Journal of Economic Dynamics and Control*, vol. 58, pp. 152-66.
- Carlson, Mark (2015). “Lessons from the Historical Use of Reserve Requirements in the United States to Promote Bank Liquidity,” *International Journal of Central Banking*, vol. 11(1), pp. 191-224.

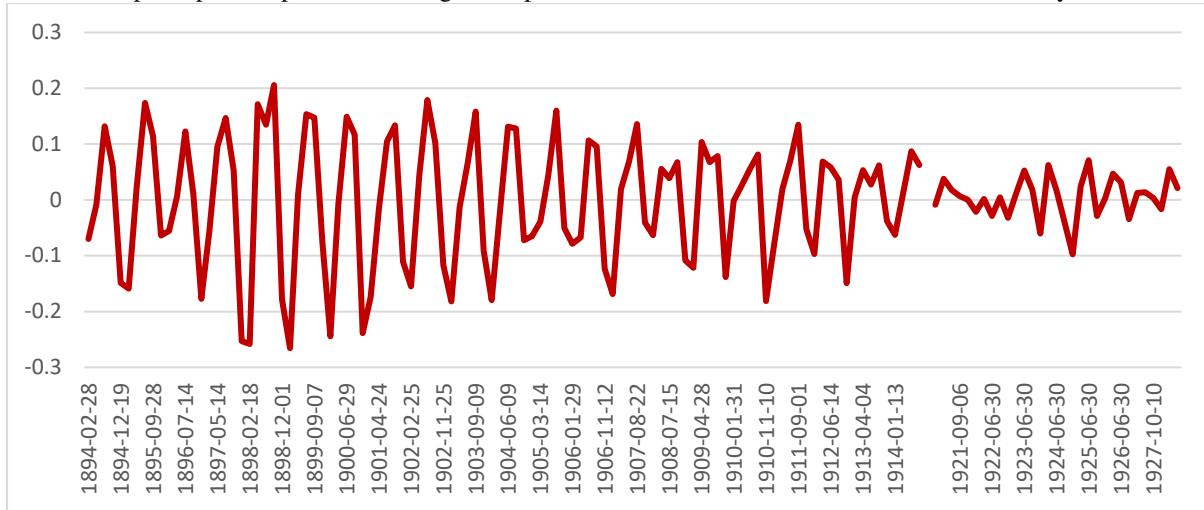
- Carlson, Mark; Mitchener, Kris James; and Gary Richardson (2011). "Arresting Banking Panics: Fed Liquidity Provision and the Forgotten Panic of 1929," *Journal of Political Economy*, vol. 119(4), pp. 889-924.
- Carlson, Mark and David C. Wheelock (2016). "Interbank Markets and Banking Crises: New Evidence on the Establishment and Impact of the Federal Reserve," *American Economic Review: Papers & Proceedings* 106(5), pp. 533-37.
- Carlson, Mark and David C. Wheelock (2015). "The Lender of Last Resort: Lessons from the Fed's First 100 Years." In Owen F. Humpage, ed., *Current Federal Reserve Policy Under the Lens of Economic History: Essays to Commemorate the Federal Reserve System's Centennial*. Cambridge: Cambridge University Press, pp. 49-101.
- Castiglionesi, Fabio; Feriozzi, Fabio; and Guido Lorenzoni (2012). "Financial Integration and Liquidity Crises." <http://www.cireqmontreal.com/wp-content/uploads/2013/03/castiglionesi.pdf> (accessed Feb 18, 2015).
- Chang, Howard H.; Danilevsky, Marina; Evans, David S.; and Daniel D. Garcia-Schwartz (2008). "The Economics of Market Coordination for the Pre-Fed Check-Clearing System: A Peek into the Bloomington (IL) Node," *Explorations in Economic History* 45 (4), September, pp. 445-61.
- Coffin, George (1896). *Handbook for Bank Officers*, McGill and Wallace: Washington DC.
- Conway, Thomas and Ernest Patterson (1914). *The Operation of the New Bank Act*, J.B. Lippincott Company: Philadelphia and London.
- Craig, Ben and Goetz von Peter (2014). "Interbank Tiering and Money Center Banks," *Journal of Financial Intermediation*, July, vol. 23(3), pp. 322-47.
- Davis, Joseph H.; Hanes, Christopher; and Paul W. Rhode (2009). "Harvests and Business Cycles in Nineteenth-Century America," *Quarterly Journal of Economics*, November, vol. 124(4), pp. 1675-1727.
- Federal Deposit Insurance Corporation. (1997) History of the Eighties, Lessons for the Future. Washington: Federal Deposit Insurance Corporation
- Friedman, Milton and Anna J. Schwartz (1963). *A Monetary History of the United States 1867-1960*, Princeton: Princeton University Press
- Gai, Prasanna; Haldane, Andrew; and Sujit Kapadia (2011). "Complexity, Concentration, and Contagion," *Journal of Monetary Economics*, vol. 58, pp. 453-70.
- Garbade, Kenneth D. (2012). *Birth of a Market: The U.S. Treasury Securities Market from the Great War to the Great Depression*. Cambridge, MA: MIT Press.
- Glasserman, Paul and H. Peyton Young (2015). "How Likely is Contagion in Financial Networks?" *Journal of Banking and Finance* 50: 383-399.
- Gorton, Gary (1985). "Clearinghouses and the Origin of Central Banking in the United States," *Journal of Economic History*, vol. 45(2), pp. 277-83.

- Gorton, Gary and Ellis W. Tallman (2016). "Too Big to Fail Before the Fed," *American Economic Review: Papers & Proceedings* 106(5), pp. 528-32.
- Haldane, Andrew (2009). "Rethinking the Financial Network," *Speech*, given at the Financial Student Association, Amsterdam, April 28, 2009.
- James, John A. (1978). *Money and Capital Markets in Postbellum America*, Princeton: Princeton University Press.
- James, John A. and David F. Weiman (2010). "From Drafts to Checks: The Evolution of Correspondent Banking Networks and the Formation of the Modern U.S. Payments System, 1850-1914." *Journal of Money, Credit and Banking* 42 (2-3): 237-265.
- James, John A.; Weiman, David F. and James McAndrews (2012). "Wall Street and Main Street: the Macroeconomic Consequences of New York Bank Suspensions," *Cliometrica*, 7(2):99-130.
- Jaremski, Matthew and David C. Wheelock (2016). "Banker Preferences, Interbank Connections, and the Enduring Structure of the Federal Reserve System." Federal Reserve Bank of St. Louis working paper no. 2015-011C.
- Kemmerer, Edwin (1910), *Season Variations in the Relative Demand for Money and Capital in the United States*, National Monetary Commission, U.S. Government Printing Office: Washington DC.
- Lowenstein, Roger (2015). *America's Bank: The Epic Struggle to Create the Federal Reserve*. Penguin Press.
- Mitchener, Kris James and Gary Richardson (2014). "Shadowy Banks and the Interbank Amplifier during the Great Depression," *mimeo*.
- Miron, Jeffrey A. (1986). "Financial Panics, the Seasonality of the Nominal Interest Rate, and the Founding of the Fed," *American Economic Review* 76 (1), March, pp. 125-40.
- Miron, Jeffrey A. and Christina D. Romer (1990). "A New Monthly Index of Industrial Production, 1884-1940," *Journal of Economic History* 50(2), June, pp. 321-37.
- Moulton, H. G. (1918). "Commercial Banking and Capital Formation, part III." *Journal of Political Economy* 26 (7), pp. 705-31.
- Odell, Kerry A. and Mark D. Weidenmier (2004). "Real Shock, Monetary Aftershock: The 1906 San Francisco Earthquake and the Panic of 1907." *Journal of Economic History* 64(4), December, pp. 1002-1027.
- Office of the Comptroller of the Currency (various). *Annual Report of the Comptroller of the Currency*. Washington, D.C.
- Owen, Robert L. (1919). *The Federal Reserve Act, Its Origins and Principles*. New York: The Century Company.
- Richardson, Gary and William Troost. (2009). "Monetary Intervention Mitigated the Banking Panics during the Great Depression: Quasi-experimental Evidence from a Federal Reserve District Border, 1929-1933," *Journal of Political Economy*, 117(6), pp. 1031-73.

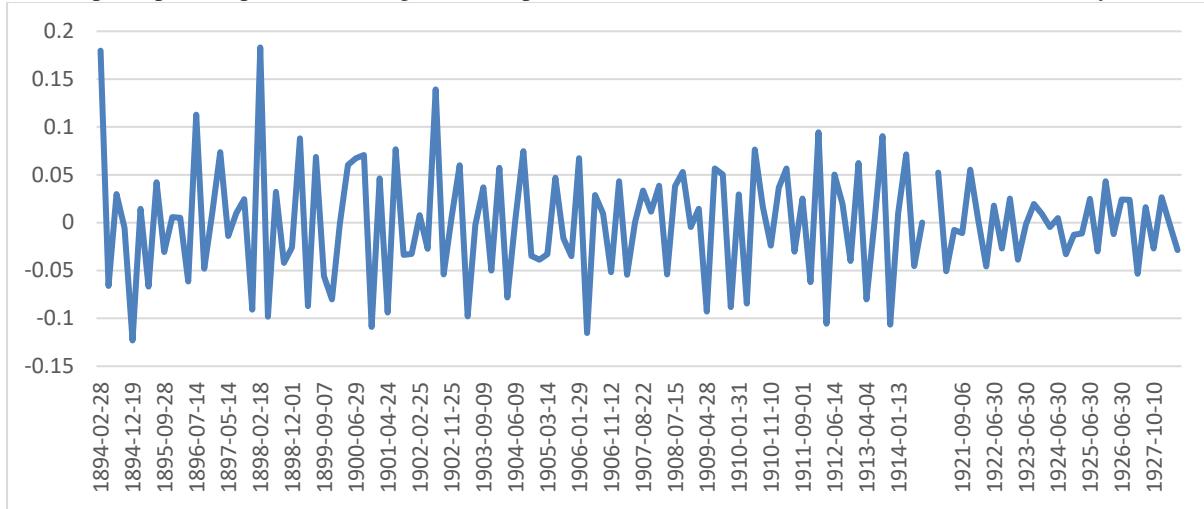
- Silber, William L. (2007). "The Great Financial Crisis of 1914: What Can We Learn from Aldrich-Vreeland Emergency Currency?" *American Economic Review Papers and Proceedings*, 97(2), May 2007, pp. 285-89.
- Sprague, O.M.W. (1908). "The American Economic Crisis of 1907," *Economic Journal*, 18(71), pp. 353-72.
- Sprague, O.M.W. (1913). *Banking Reform in the United States*. Cambridge: Harvard University Press.
- United States Congress (1912-13). *The Money Trust Investigation: Investigation of Financial and Monetary Conditions in the United States Under House Resolutions Nos. 429 and 504 Before a Subcommittee of the Committee on Banking and Currency, House of Representatives*. (<https://fraser.stlouisfed.org/title/80#23658>)
- Vanderlip Frank (1908). "The Panic as a World Phenomenon," in *Lessons of the Financial Crisis, Annals of the American Academy of Political and Social Science*, 31(2).
- Warburg, Paul (1916). "The Reserve Problem and the Future of the Federal Reserve," Speech before the Convention of the American Bankers Association, Kansas City, Missouri, September 29.
- Wheelock, David C. (1992). "Seasonal Accommodation and the Financial Crises of the Great Depression, *Federal Reserve Bank of St. Louis Review* 74(6), November/December 1992, pp. 3-18.
- Wicker, Elmus (2000). *Banking Panics of the Gilded Age*. Cambridge: Cambridge University Press.

Figure 1: Interbank Deposit Flows

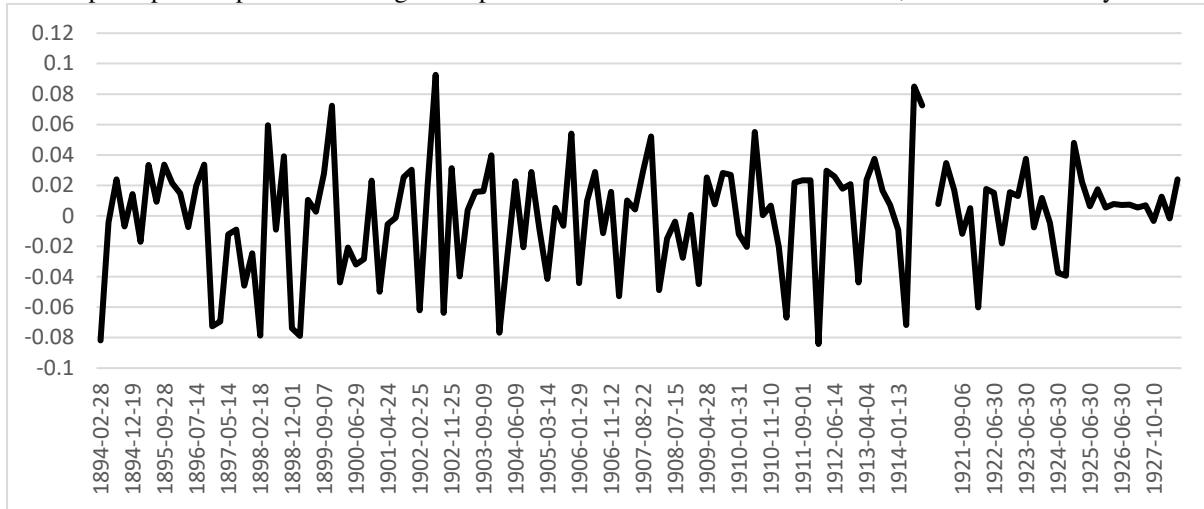
First principal component of change in deposits due from national banks/total assets, country banks



First principal component of change in net deposits due from national banks/total assets, reserve city banks



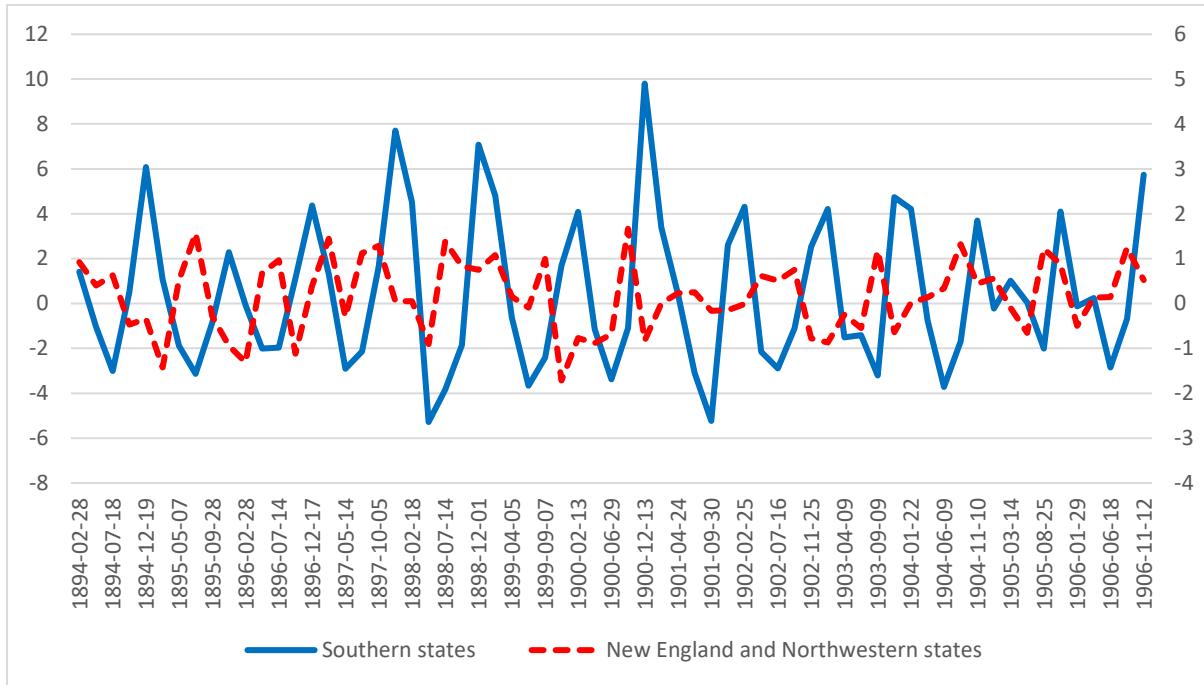
First principal component of change in deposits due to national banks/total assets, central reserve city banks



Note: The figure plots the first principal component of the indicated change in interbank deposits (scaled by total assets) between call report dates. Country bank data are aggregated at the state level. Reserve city and central reserve city data are aggregated at the city level. The source for these data are *Annual Reports* of the Office of the Comptroller of the Currency.

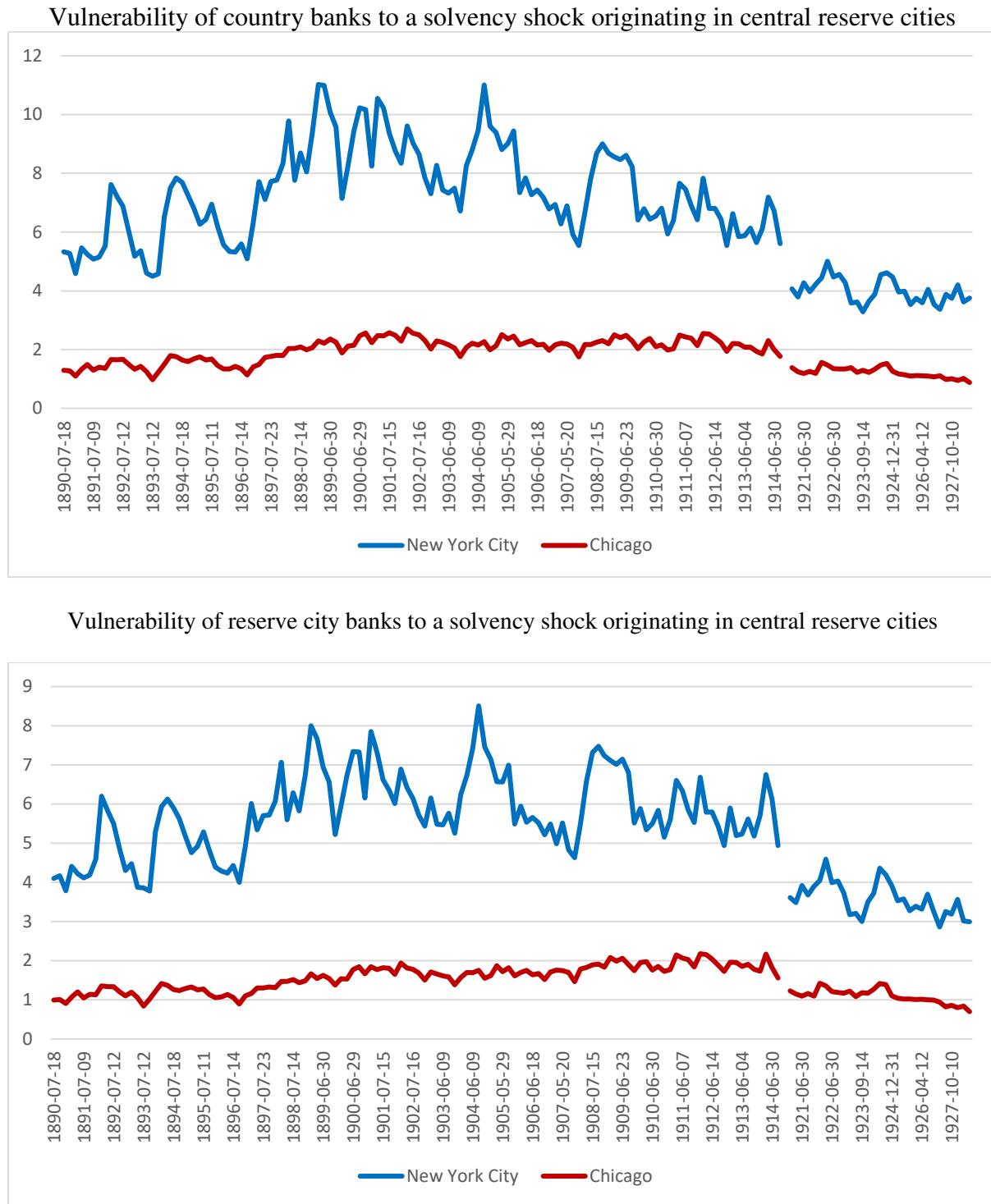
Figure 2

Change in deposits due from national banks for different regions



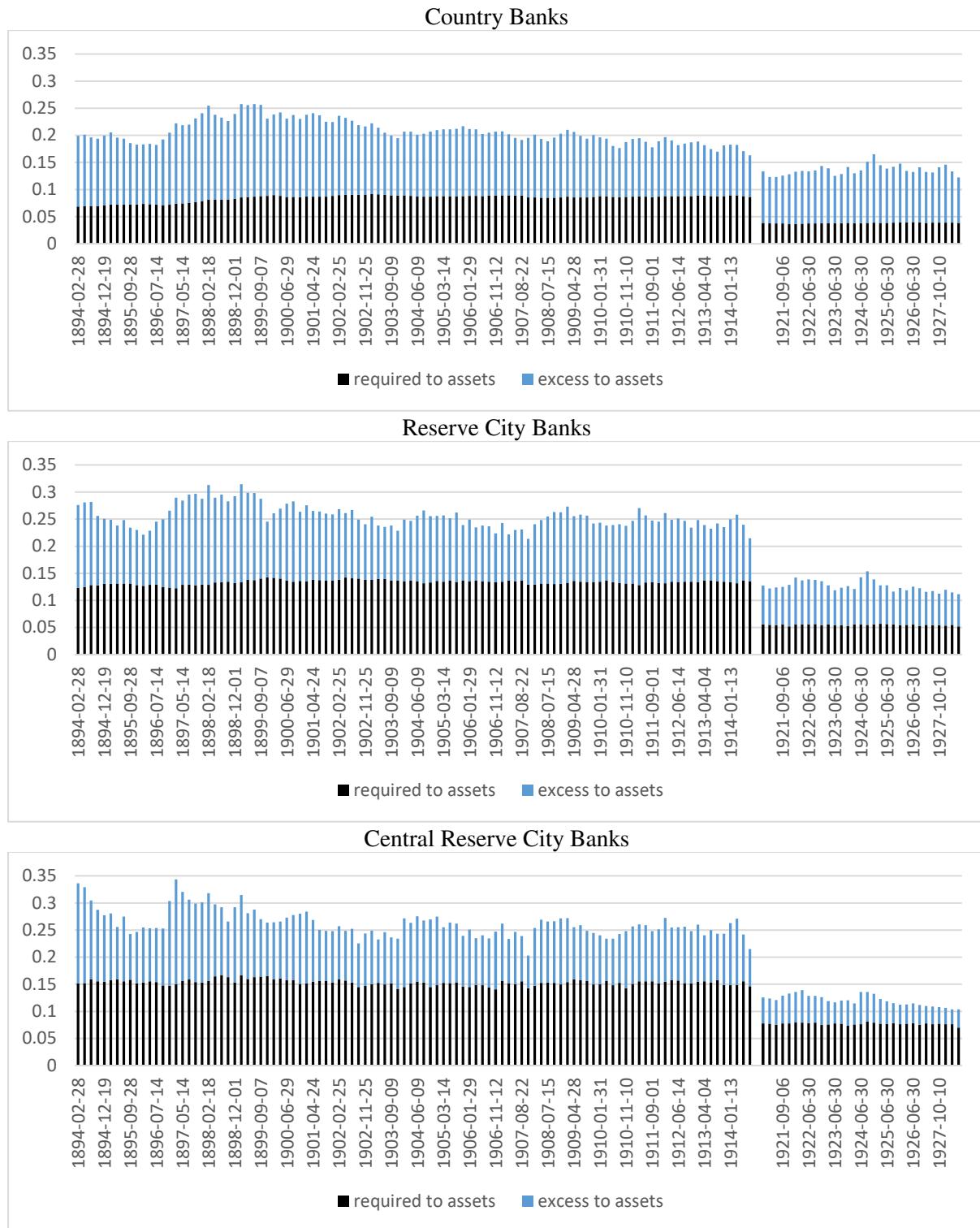
Note. The figure plots the change in deposits due from national banks (scaled by total assets) between call report dates for country banks located in the indicated regions. The data are aggregated at the state level. The source for these data are *Annual Reports* of the Office of the Comptroller of the Currency.

Figure 3



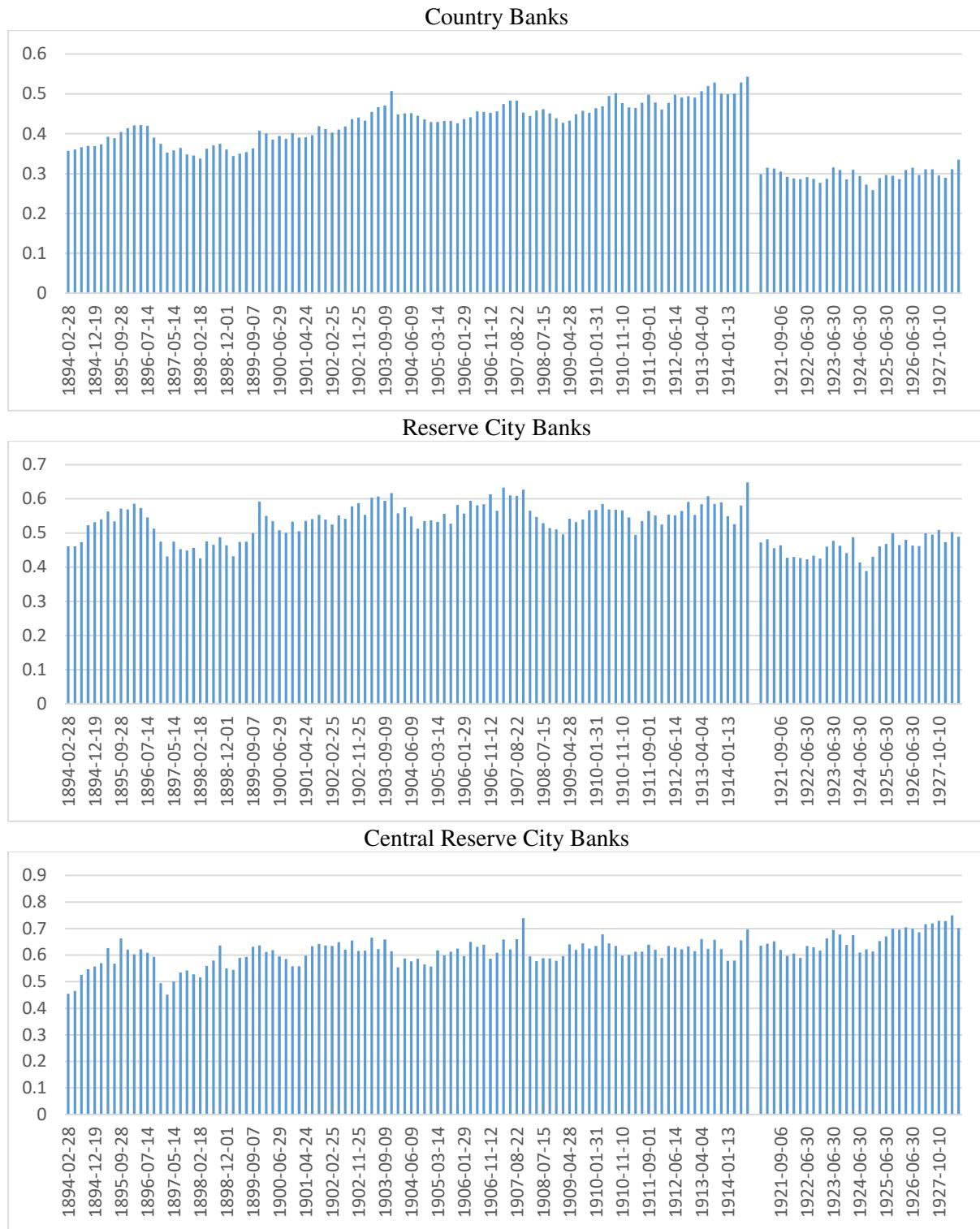
Note. The panels plot the average vulnerability of country banks (top panel) and reserve city banks (bottom panel) to a solvency shock originating in New York City or Chicago, as defined in the text.

Figure 4
Required Reserves and Excess Liquid Assets as a Share of Total Assets



Note. The figure plots group average values of required reserves and excess liquid assets to total assets as defined in the text. Data for country banks are aggregated at the state level. Data for reserve city and central reserve city banks are aggregated at the city level. The source for these data are *Annual Reports* of the Office of the Comptroller of the Currency.

Figure 5
Required Reserves as a Share of Total Liquid Assets



Note. The figure plots group average values of required reserves to total liquid assets as defined in the text. Data for country banks are aggregated at the state level. Data for reserve city and central reserve city banks are aggregated at the city level. The source for these data are *Annual Reports* of the Office of the Comptroller of the Currency.

Figure 6

Estimated panic withdrawals at reserve city banks as a percentage of liquid assets

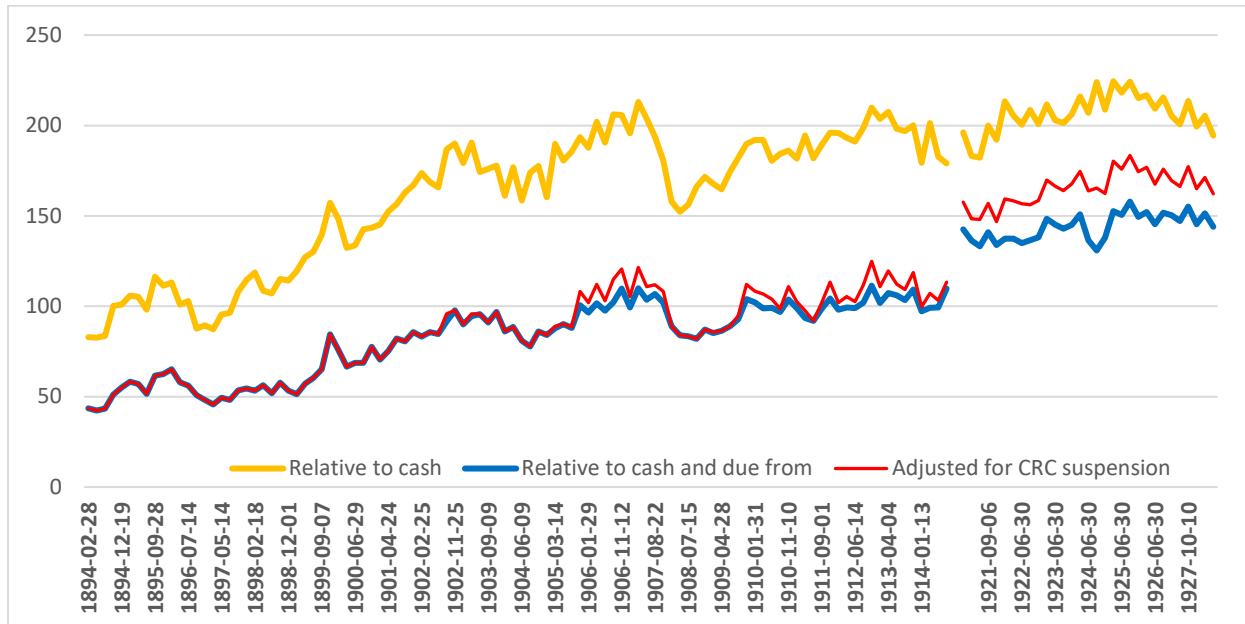
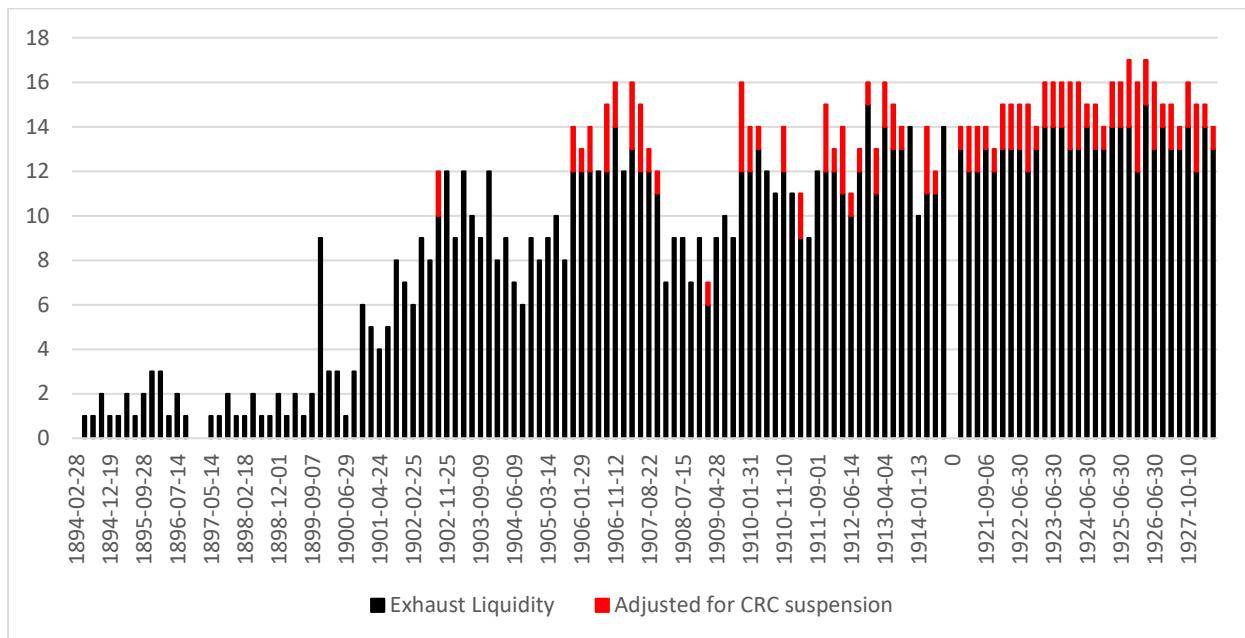


Figure 7

Number of reserve cities that would exhaust liquid assets in a panic



Note: Figure 6 plots estimated withdrawals in a panic event (as defined in the text) at reserve city banks as a percentage of their cash, cash and deposits due from agents, and cash and deposits due from agents adjusted for suspensions by central reserve city (CRC) banks on each call report date. Figure 7 plots the number of reserve cities where the total liquid assets (cash and deposits due from agents) of national banks was less than the estimated withdrawals in a panic event on each call report date.

Figure 8

Estimated panic withdrawals at central reserve city banks as a percentage of cash assets

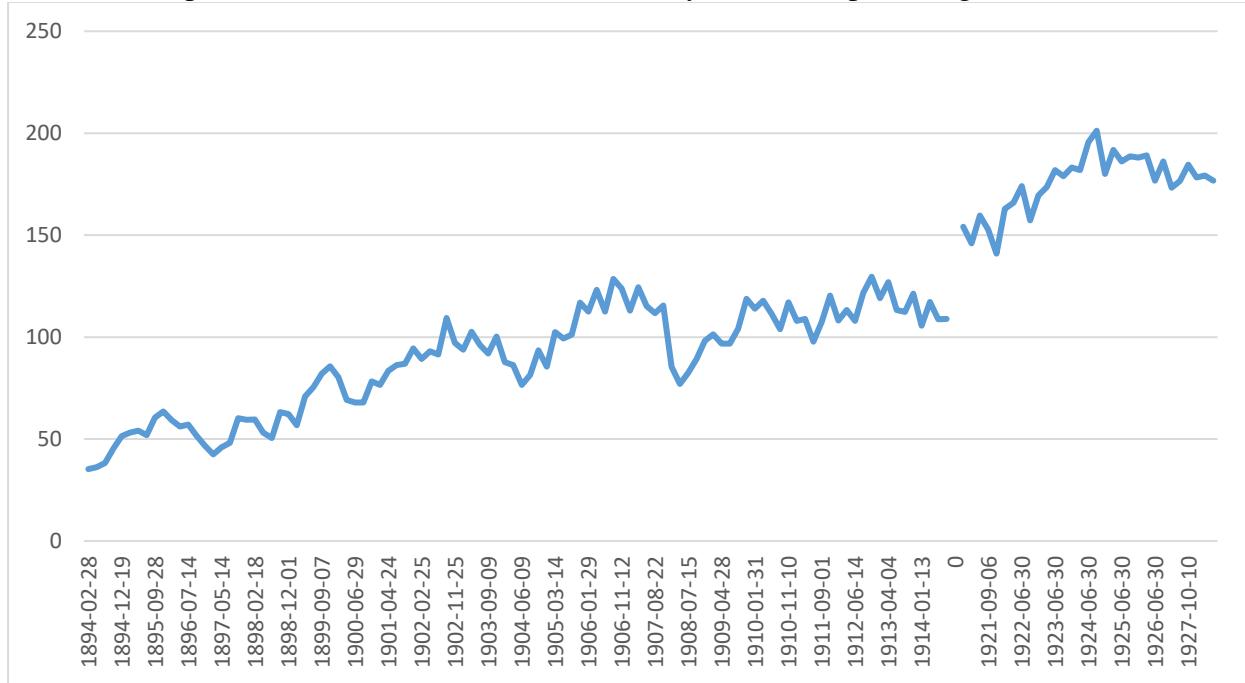
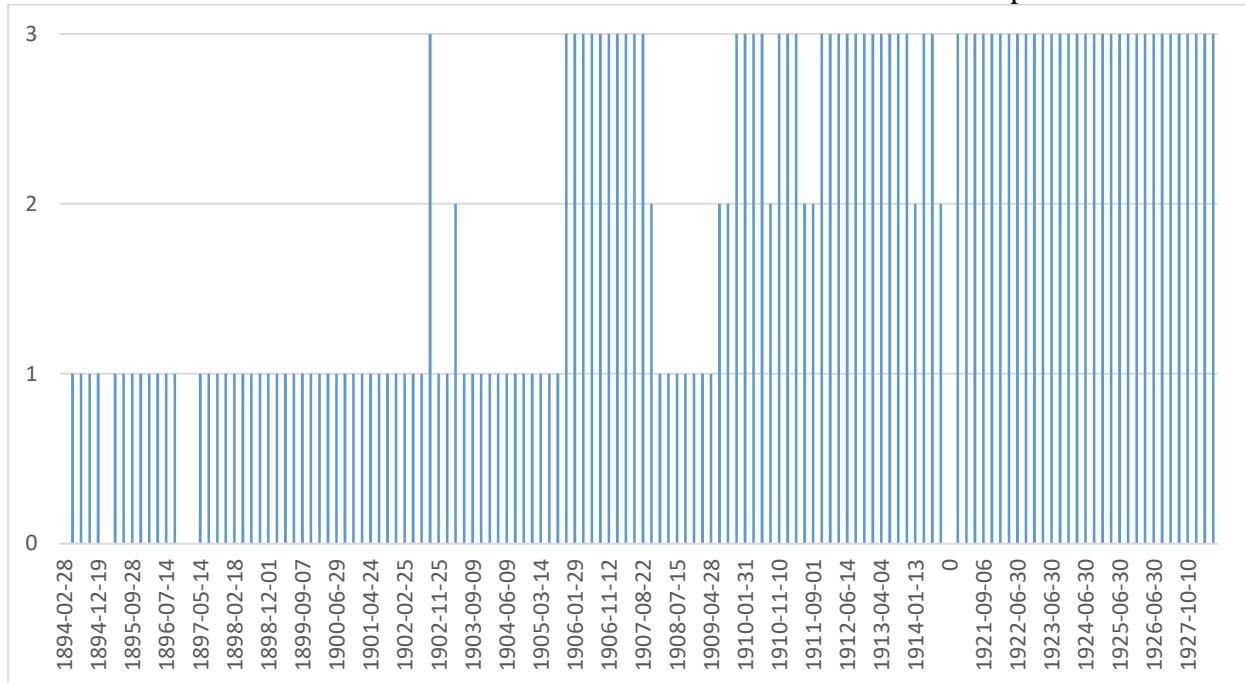


Figure 9

Number of central reserve cities that would exhaust cash assets in a panic



Note: Figure 8 plots estimated withdrawals in a panic event (as defined in the text) at central reserve city banks as a percentage of their total cash assets on each call report date. Figure 9 plots the number of central reserve cities where the total cash assets of national banks was less than the estimated withdrawals in a panic event on each call report date.

Table 1
Interbank Deposit Volumes

	1894 – 1914	1921 – 1928	T-statistic for difference
Country Banks:			
1 Deposits due from national bank correspondents as a share of total assets	13.8 (5.0)	6.8 (3.2)	-21.8***
2 Reserve City Banks: Deposits due from national bank correspondents as a share of total assets	16.1 (5.3)	5.2 (3.0)	-12.5***
3 Reserve City Banks: Deposits due to national bank respondents (scaled by total assets)	14.1 (7.2)	7.4 (4.2)	-5.6***
4 Central Reserve City Banks: Deposits due to national bank respondents (scaled by total assets)	24.1 (4.3)	9.4 (2.9)	-23.7***
5 Central reserve city banks' share of deposits due to national banks in central reserve cities and 18 reserve cities	64.6 (2.1)	58.7 (1.9)	-14.9***
6 Central reserve city banks' share of total assets of national banks in central reserve cities and 18 reserve cities	53.5 (1.9)	56.6 (1.6)	8.8***
Number of call reporting dates in period	104	31	

Note. The table reports averages and standard deviations (in parentheses) of data pooled across location and time for banks in the indicated bank group(s), with the number of observations determined by the number of call reporting dates in the given period. Data for country banks are pooled state-level observations for 48 states. Data for reserve city banks are pooled city-level observations for 18 reserve cities. Data in row 4 for central reserve city banks are pooled city-level observations for the three central reserve cities. Shares reported in rows 5 and 6 reflect a single observation per call report. T-statistics in the right hand column for rows 1-4 are computed from regressing the ratio on an indicator for the observation occurring after 1920 and state/city indicator variables with standard errors clustered at the location level. T-statistics for rows 5 and 6 are based on the reported means and standard deviations. The symbol *** indicates statistical significance at the 1 percent level. The source for these data are the *Annual Reports* of the Office of the Comptroller of the Currency.

Table 2
Seasonal Patterns in Federal Reserve Credit

Dependent variable: Federal Reserve Credit

	Coefficient	SE
January	179.6	(131.1)
February	192.6	(132.1)
March	213.3	(129.5)
April	141.9	(131.0)
May	253.0**	(121.4)
June	235.1*	(122.5)
July	200.9*	(120.6)
August	337.0***	(113.4)
September	450.7***	(115.0)
October	376.4***	(126.3)
November	440.7***	(125.5)
December	508.1***	(129.2)
Industrial Production	6.6***	(1.1)
Time trend	-3.0***	(0.8)
Observations	116	
Adjusted R ²	.91	

Note. The table reports an ordinary least squares regression of Federal Reserve credit (defined here as the sum of Federal Reserve discount window loans outstanding and holdings of bankers acceptances) on monthly dummy variables, an index of industrial production, and a linear time trend. Industrial production is the level of the Miron and Romer (1990) index of industrial production minus its January 1915 value. The symbols ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels respectively. The regression is estimated using end of month data for January 1922 – August 1931. The source for data on Federal Reserve credit is the *Federal Reserve Bulletin* (Board of Governors of the Federal Reserve System, various).

Table 3
 Interbank Deposit Flows in Normal and Panic Periods
 (In percentage points)

	Average change May to Oct. 1894-1906	Change from May to Oct. 1893	Average change Aug. to Dec. 1894-1906	Change from Aug. to Dec. 1907
<i>Country banks: due from national banks scaled by own total assets</i>				
1 All country banks	0.6	-2.5	0.5	-1.2
2 New England & Mid-Atlantic	1.3	0.5	-0.6	-0.2
3 Upper Midwest	1.2	-1.7	-0.8	-2.9
4 South	-4.1	-4.6	3.5	0.9
5 Plains	2.5	-2.0	0.0	-1.3
6 West	3.1	-5.0	0.1	-3.8
<i>Country banks: due from national banks scaled by total assets of banks in reserve cities and central reserve cities</i>				
7 All county banks	0.4	-1.7	0.0	-1.7
<i>Reserve city and central reserve city banks: due to national banks scaled by own total assets</i>				
8 Reserve city banks	1.0	-2.7	-0.2	-2.7
9 Central Reserve city banks	-0.2	-3.3	-0.3	-2.6

Note. The table presents the change in interbank deposits over the indicated period scaled by total assets at the start of the period. The averages are calculated by first averaging across states (for country banks) or cities (for reserve city and central reserve city banks) and then over the indicated periods. The source for these data are *Annual Reports* of the Office of the Comptroller of the Currency.

State groupings:

New England & Mid-Atlantic states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia.

Upper Midwest: Illinois, Indiana, Kentucky, Michigan, Missouri, Ohio, West Virginia, Wisconsin

South: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas.

Plains: Colorado, Iowa, Kansas, Minnesota, Nebraska, North Dakota, South Dakota, Wyoming.

West: Arizona, California, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington.

Table 4
 Average Values of Contagion Vulnerability Index and Components

Vulnerability Index (Contagion _j /Resilience _i)	1890 – 1914	1921 – 1928	Test statistic for difference
Country banks:			
With respect to New York City	7.4 (1.6)	4.0 (0.4)	-8.5***
With respect to Chicago	2.0 (0.4)	1.2 (0.2)	-7.6***
Reserve city banks:			
With respect to New York City	5.8 (1.0)	3.6 (0.4)	-8.3***
With respect to Chicago	1.6 (0.3)	1.1 (0.2)	-6.6**
Interconnectedness			
New York City banks	0.4 (0.0)	0.2 (0.0)	-8.6***
Chicago banks	0.5 (0.0)	0.3 (0.0)	-8.5***
Leverage			
Country banks	3.4 (0.7)	6.7 (0.4)	8.6***
Reserve city banks	4.2 (0.8)	7.7 (0.8)	8.6***
New York City banks	6.2 (1.0)	8.0 (0.6)	7.2***
Chicago banks	5.8 (1.2)	8.0 (1.0)	7.1***

Note. The table reports averages and standard deviations (in parentheses) for the indicated period of the contagion vulnerability index described in the text, i.e., Contagion_j/Resilience_i, where Contagion_j is defined in Equation (1) and Resilience_i is defined in Equation (2). The table also reports averages and standard deviations of the interconnectedness measure used in Equation (1) for New York City and Chicago central reserve city banks, and the leverage measure used in Equation (1) for New York City and Chicago banks and the leverage measure used in Equation (2) for country and reserve city banks. A Wilcoxon rank-sum test is used to determine whether differences between the two periods are statistically significant; we report the z-score test statistic. The symbols *** and ** indicate statistical significance at the 1 percent and 5 percent levels, respectively.

Table 5

Liquidity at National Banks Before and After the Founding of the Fed (Percent of Assets)

	1894 – 1914	1921 – 1928	Test statistic for difference
Liquid Assets/Total Assets	Average (standard deviation)	Average (standard deviation)	
Country Banks	20.7 (6.0)	13.6 (3.8)	-17.6***
Reserve City Banks	25.6 (5.3)	12.6 (3.4)	-18.8***
Central Reserve City Banks	26.3 (4.6)	12.0 (2.8)	-12.8***
Required Reserves/Total Assets			
Country Banks	8.5 (1.4)	3.8 (0.4)	-30.8***
Reserve City Banks	13.4 (1.5)	5.5 (0.5)	-34.0***
Central Reserve City Banks	15.3 (1.4)	7.7 (0.7)	-13.9*
Required Reserves/Liquid Assets			
Country Banks	43.2 (11.2)	29.7 (6.8)	-14.8***
Reserve City Banks	54.1 (10.3)	46.3 (10.7)	-3.5***
Central Reserve City Banks	60.3 (12.4)	66.3 (11.4)	1.6
Excess Liquid Assets/Total Assets			
Country Banks	12.2 (5.5)	9.8 (3.5)	-7.0***
Reserve City Banks	12.2 (5.1)	7.1 (3.4)	-6.9***
Central Reserve City Banks	10.9 (4.9)	4.3 (2.4)	-4.0*
Excess Reserves/Total Reserves			
Country Banks	46.5 (12.9)	8.2 (5.3)	-30.3***
Reserve City Banks	25.5 (15.9)	-0.1 (19.7)	-10.0***
Central Reserve City Banks	7.0 (11.3)	0.7 (5.5)	-7.4*
Number of call reporting dates in period	104	31	

Note. The table reports averages and standard deviations (in parentheses) of data for banks in the indicated bank group(s) pooled across location and over time, with the number of observations determined by the number of call reporting dates in the given period. Data for country national banks are pooled state-level observations for the 48 states. Data for reserve city banks are pooled city-level observations for 18 reserve cities. Data for central reserve city banks are pooled city-level observations for the three central reserve cities (except for excess reserves/total reserves, which are for Chicago and New York City only). T-statistics in the right hand column are computed from regressing the ratio on an indicator for the observation occurring after 1920 and state/city indicator variables with standard errors clustered at the location level. The symbols ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels respectively. The source for these are *Annual Reports* of the Office of the Comptroller of the Currency.

Table 6

Average Values of the Size of Panic Withdrawals as a Percentage of Available Liquidity

	1894-1914	1921-1928	T-statistic for differences
Country banks: relative to cash on hand	195.9 (42.6)	236.4 (10.6)	8.8***
Country banks: relative to cash on hand and deposits due from banks	72.5 (12.3)	136.3 (8.4)	33.0***
Reserve city banks: relative to cash on hand	158.9 (37.6)	206.5 (10.6)	11.5***
Reserve city banks: relative to cash on hand and deposits due from banks	82.0 (20.0)	143.9 (7.3)	26.3***
Central reserve city banks: relative to cash on hand	88.6 (25.5)	175.3 (14.5)	24.0***

Note. The table reports sample period averages and standard deviations (in parentheses) of the percentage of available liquidity (either cash on hand or cash on hand plus deposits due from banks) required to meet a panic shock calibrated to the Panic of 1893, as described in the text. A value exceeding 100 indicates that the shock would more than deplete the average liquid assets of the indicated group of banks. Given the construction of the shocks, cash on hand, deposits, and withdrawals are aggregated across locations of a given type (states/cities) and the mean and standard deviation are calculated over time. T-statistics are based on the reported means and standard deviations with 104 call reports pre-Fed and 31 call reports post-Fed. The symbol *** indicates statistical significance at the 1 percent level.