Interbank Networks in the Shadows of the Federal Reserve Act*

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Abstract

How does public liquidity provision reshape shadow banks' portfolios and interbank networks? We study this question using new data from Virginia state-bank examination reports around the creation of the Federal Reserve in 1913. After the Fed's creation, nonmember "shadow" banks held fewer liquid assets, borrowed more from other banks, and shifted correspondent relationships away from national financial centers toward local partners. We develop a model in which indirect access to public liquidity weakens the value of private liquidity insurance, explaining these portfolio and network changes. Consistent with this mechanism, we document that during the 1921 recession, Fed member banks passed Federal Reserve liquidity to nonmembers, especially through rural links. We then use the model to quantify the trade-off between public liquidity provision and regulation, and to study its implications for financial stability and investments.

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1 Introduction

The Federal Reserve System and other central banks have infused large amounts of liquidity in recent years, most notably during the 2008 financial crisis, the 2012 Eurozone sovereign debt crisis, and the 2020 COVID-19 pandemic. These interventions, introduced to stabilize financial markets, have prompted calls for more stringent regulation of financial intermediaries with direct access to public liquidity. Evaluating this recommendation, however, requires understanding how public liquidity provision also affects the behavior of *unregulated* intermediaries without direct access to public liquidity. How does public liquidity affect the operations of - and interactions between - regulated and unregulated banks? What is the optimal combination of public liquidity provision and regulatory requirements once their effects on interbank networks are taken into account? What are the ultimate implications for total investments and financial stability?

Answering these questions is challenging. One obstacle is the ubiquitous presence of central banking, which prevents a cross-country comparison of interbank networks with and without public liquidity provision. Another obstacle is the complexity of modern financial markets, which makes it difficult to document how interbank networks respond to changes in central bank policies. A third obstacle is identifying banks' expectations about central bank policies under different circumstances and shocks. These challenges are even more pronounced for unregulated financial intermediaries, which lack direct access to public liquidity and, as a result, avoid regulatory oversight.

In this paper, we address these challenges by turning to historical data. We study the interbank network before and after the introduction of the Federal Reserve System in 1913, which was established to provide liquidity to member banks through the discount window. Membership was compulsory for national banks but voluntary for state banks, and most state banks remained outside the System. A central historical feature of this environment is that nonmembers could still obtain liquidity indirectly through member correspondents while avoiding the tighter regulation and supervision associated with membership (see Anderson et al. (2018) and Carlson and Wheelock (2018a)). This institutional arrangement created a setting in which nonmember banks relied on interbank connections to obtain liquidity, enabling the study of how public liquidity and private interbank insurance interact.

Despite the importance of nonmember banks in the banking system (70% of all banks and 30% of all loans), little is known about how their interbank relationships shape their portfolios and their interbank positions. We construct a unique dataset of state banks in Virginia spanning the creation of the Federal Reserve Act and the 1921 recession (1911 and 1920-1922). These data come from state examination reports, which provide detailed information on banks' assets, liabilities, and counterparties. Almost none of these banks decided to become Fed members. On the asset side, we observe cash holdings, deposits in other banks, bonds, and loans. On the liability side, we observe equity, household deposits, and short-term borrowing from other banks.

On interbank relationships, we observe both the *interbank deposit network* (amount of deposits due from each correspondent) and the *interbank borrowing network* (amount of short-term borrowing from each correspondent).[1] To the best of our knowledge, this is the first dataset that provides a *complete* picture of state/nonmember banks' interbank deposit and interbank borrowing networks. Although the sample is restricted to Virginia, our data contrast with existing studies that only report total interbank amounts - without disaggregation by individual correspondent bank - or use correspondent links without knowing the function and strength of those relationships.[2]

Our first set of findings shows that after the Fed's creation, nonmember banks relied more on interbank loans and less on interbank deposits. This pattern closely mirrors the behavior of member banks documented by Carlson and Wheelock (2018a), despite nonmembers lacking direct access to the discount window and despite not being subject to regulations prohibiting the use of correspondent deposits to meet reserve requirements.[3]

We also document structural changes in the interbank network after the Fed's creation. First, the interbank deposit network became less centralized, with nonmember banks reducing their reliance on financial centers such as New York, historically a pool of interregional deposits and a source of cross-region liquidity insurance (Carlson and Wheelock, 2018a). Second, the interbank borrowing network also became increasingly local, despite being more localized to begin with (Redenius and Weiman, 2011).

We then document how this transformed network performed during the 1921 recession, the first major stress test of the Federal Reserve System. The recession sharply intensified liquidity strains in the rural South: cotton prices fell 70%, farm incomes dropped 60%, and many

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[1] Banks placing deposits in other banks were called respondents, and banks receiving deposits were called correspondents. Our focus is on liquidity management through correspondent balances and short-term credit, not on payment-settlement technology such as check clearing or float.

[2] Commercial bank directories such as *Rand McNally* and *Polk*, for instance, provide information on self-reported correspondent linkages (and sometimes the names of counterparties), but not the types or amounts associated with these transactions. Further, while several studies have examined how interbank deposits contributed to financial contagion, only recently has attention turned to the role of interbank borrowing, such as Lockhart (1921a), Lockhart (1921b), Calomiris and Carlson (2014), and Redenius and Weiman (2020).

[3] We are not able to formally test whether the Fed caused or contributed to changes in nonmember banks' balance sheets and network structure, but we provide evidence on *nonmember banks* that is consistent with prior research focusing on *member banks*, such as Carlson and Wheelock (2018b), Carlson and Wheelock (2018a), and Jaremski and Wheelock (2020), and model a rationale for this result.

state nonmember banks - with undiversified cotton loan portfolios and no direct access to the discount window - faced acute liquidity shortfalls. We measure the extent to which Federal Reserve liquidity reached nonmember banks indirectly through their member correspondents. On average, Virginia member banks passed through roughly 20% of discount-window funds to nonmembers in 1920, rising to 40% at the recession's peak in 1921, and returning to 20% in 1922. Critically, this pass-through was driven by rural member banks rather than by member banks in large cities such as Richmond or Norfolk.

These shifts in the interbank system are relevant for financial stability. They raise the possibility of *upstream contagion* (nonmembers are more likely to appeal to members for funds) and *downstream contagion* (members' liquidity shocks deplete public liquidity and may limit the funds available to nonmembers). These two-sided exposures motivate our model of endogenous portfolios and interbank connections, which we use to interpret how public liquidity changed the role of the interbank system and to discipline a quantitative exercise on the trade-off between public liquidity provision and reserve requirements.

In the model, a nonmember bank faces liquidity shocks in the form of retail deposit withdrawals. In the absence of public liquidity, the bank follows two strategies to prevent costly asset liquidations. First, it allocates investment according to a pecking order: loans, interbank deposits, and cash. When the bank faces a larger likelihood of withdrawals, it chooses to hold fewer loans and more interbank deposits and cash. Second, the bank accesses other banks' idle liquidity through well-connected counterparties. The first motive generates a *precautionary response*, in which the bank deposits funds with other banks and foregoes financing more profitable investment opportunities. The second motive generates a *reactionary response*, in which it borrows from other banks only in response to a withdrawal shock. This framework is consistent with a branch of the literature, such as Allen and Gale (2000) and Freixas et al. (2000), which argues that a connected network provides liquidity insurance against shocks to individual banks. We extend this framework by endogenizing both individual portfolio choices and interbank connections.

Once public liquidity is introduced (in our application, through the creation of the Federal Reserve System that provides liquidity only to member banks), the nature and structure of the interbank system change for two reasons. First, *the nature of liquidity management changes*: less diversification through interbank deposits and more borrowing of public liquidity (members directly from the Fed and nonmembers indirectly from members). Access to public liquidity allows banks to address liquidity shocks by borrowing, reducing the need to hold as much cash and interbank deposits, and allowing greater investment in illiquid assets. This change in bank portfolios altered the interbank system from a *tool for diversification* to a *pipeline to public funds.* Second, *the structure of the interbank system changes*: banks no longer need to hedge against withdrawals by securing liquidity through counterparties in other regions. In response, banks increase their reliance on local member correspondents - who are cheaper due to shorter distances, better information, stronger relationships - making the interbank network more locally oriented, *crowding out private inter-regional insurance.* In short, financial center banks shift from being *providers of private liquidity insurance* to *conduits for public liquidity insurance.*

Although public liquidity provision makes the overall network more resilient to idiosyncratic shocks, it can also leave it more exposed to systemic disturbances. Under normal circumstances, public liquidity helps banks avoid costly liquidations when they face individual withdrawal shocks. At the same time, the endogenous response of banks may shift more risk onto balance sheets and into more localized interbank structures. This distinction helps organize the paper's main message. We use *vulnerability* to denote a bank's need to rely on outside liquidity to avoid liquidation after a withdrawal shock, so vulnerability rises when private liquidity falls relative to illiquid assets. We use *fragility* to denote the probability of liquidation conditional on a withdrawal shock, which depends on total liquidity available, both private and public. Our evidence points clearly to greater vulnerability for nonmembers after the Fed. Its implications for fragility are less direct, as they depend on how much public liquidity member correspondents were willing and able to pass through.

We use an extended version of the model to discipline this trade-off between public and private liquidity, and to assess the effects on fragility. Public liquidity is valuable because it can be deployed in response to shocks, but it may also be distortionary, hence socially costly. Private liquidity in the form of reserves is not distortionary in the same way, but it is costly ex ante because it prevents the financing of superior investment opportunities, whether or not a shock occurs. We use this framework in a quantitative exercise to assess how the balance between public liquidity provision and reserve requirements shifts once the indirect use of Federal Reserve liquidity by nonmembers is taken into account. We find that a Fed concerned with both total investment and total fragility, by both members and nonmembers, would have provided more public liquidity while imposing less reserve requirements. Although our result is based on a calibration to historical data, it runs counter to the recent trend of increasing regulatory requirements for member banks when providing additional public liquidity.

Related Literature: Our paper contributes to the literature examining how the founding of the Fed affected the banking system. A set of studies has focused on member banks and their portfolio adjustments following the Federal Reserve Act. These studies document a large decline in the average volume of member banks' interbank deposits, enabling them to operate with smaller liquid buffers (Anderson et al. (2018), Carlson and Wheelock (2018b), Carlson and Wheelock (2018a)). These studies highlight the emergence of new systemic risk associated with lower private liquidity in the banking system. We show that a related force extends to nonmembers through their endogenous response to indirectly available public liquidity: nonmembers held less private liquidity, became more vulnerable, and altered their interbank connections in ways that could amplify systemic stress. Other studies examine the structural changes of *interbank deposit networks* upon the Federal Reserve Act, using correspondent linkage information from *Rand McNally Directory* (Jaremski and Wheelock (2020), Das et al. (2018)). These studies cannot distinguish interbank deposits from interbank borrowing, nor can they measure the intensive margin of these relationships. In contrast, we observe both networks and the strength of each link.

On the theoretical front, our paper relates to the literature on endogenous financial networks and government interventions. One strand studies how regulation and public support affect the incentives to form interbank links. For example, Erol and Ordoñez (2017) show that liquidity and capital requirements can weaken network structures that provide private insurance against liquidity shocks. More recently, Chang and Zhang (2021) examine how regulation shapes equilibrium network structures while taking balance sheets as given, whereas Shu (2021) study how network structure affects balance sheets while taking the network as given. Our contribution is to bring these two margins together in a unified framework: banks choose both their portfolios and their counterparties, so public liquidity and regulation jointly affect the amount of liquidity banks hold and how it is organized across the network.

Our paper also speaks to the literature on network architecture, concentration, and contagion. Classic contributions such as Allen and Gale (2000) and Freixas et al. (2000) show that denser or more complete interbank structures can improve liquidity insurance but can also transmit shocks more broadly. More recently, Acemoglu et al. (2015) characterize how incomplete financial networks can either absorb or amplify shocks depending on their configuration, while Altinoglu and Stiglitz (2021) emphasize that interbank connections can also create collective moral-hazard problems when institutions expect support from other banks or from the public sector. Relatedly, Erol (2018) shows that uncapped ex-post liquidity provision can induce greater centralization by mitigating insolvency contagion through core banks. Our mechanism is different: ex-ante public liquidity provision reduces the value of private liquidity coinsurance from core correspondents and thereby induces a less centralized network.

This perspective also connects our paper to the literature on interbank networks and systemic risk, such as Allen et al. (2012), Acemoglu et al. (2015), and Calomiris and Carlson (2017), and to the historical literature on the evolution of correspondent banking networks, including

James and Weiman (2010), Carlson and Wheelock (2018a), and Jaremski and Wheelock (2020). Empirically, Anderson et al. (2019), Calomiris et al. (2019), and Mitchener and Richardson (2019) show how the concentration and amplification properties of interbank claims shaped systemic risk. Our contribution is to connect those issues to a setting in which both portfolios and links are endogenous, and to provide new evidence that separately identifies the interbank deposit and interbank borrowing networks of nonmember banks.

The remainder of the paper is organized as follows. Section 2 provides historical background on the functioning of the interbank system before and after the passage of the Federal Reserve Act. Section 3 presents our novel historical dataset and documents empirical evidence of (i) an increase in nonmember banks' use of short-term borrowing, (ii) a reduction in their liquidity, both cash and interbank deposits, and (iii) changes in the geographical structure of the core-periphery network. Section 4 examines the extent to which members pass public liquidity to nonmembers during the 1920-1921 recession. Motivated by this suggestive mechanism, Section 5 develops a benchmark model of a correspondence relationship between two banks and their portfolio choices, and then gradually extends it to incorporate a central bank, more banks, and a richer endogenous network structure. Section 6 calibrates an extended version of the model to study the optimal combination of public liquidity provision and reserve requirements when the Fed internalizes the whole reaction of the interbank network. Section 7 concludes. All proofs are contained in Appendix A.

2 Historical Background

During the National Banking Era (1864-1912), the U.S. banking system experienced frequent episodes of banking panics. Large increases in the supply of deposits during agricultural harvest seasons and the demand for credit during agricultural planting seasons created strong seasonal liquidity pressures in spring and fall, and panics occurred at times of the year in which these pressures peaked.

The interbank system of this period, facilitated by a network of correspondent deposits and short-term funding, played a crucial role in alleviating these liquidity pressures. The reserve structure during the National Banking Era involved national and state banks and was often described as an inverted pyramid: rural banks (country banks in agricultural regions) held their reserves in the form of correspondent balances (mostly, but not exclusively) in banks in central reserve cities, especially New York City.[4] The concentration of interbank deposits

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[4] The interbank system developed to overcome branching restrictions and facilitate interregional payments of goods and services. The National Banking Act institutionalized the interbank system by classifying banks

in New York City banks effectively transformed them into core institutions to reallocate liquidity across regions. When rural banks faced seasonal demand, they withdrew their interbank deposits from financial centers, drawing funds from other banks in areas with less pressing seasonal demand. Geographic differences in seasonal demand produced offsetting flows of interbank deposits in New York City banks, effectively providing private insurance across regions (Kemmerer (1910) and Carlson and Wheelock (2018a)). The interbank system helped banks meet seasonal liquidity pressures not only by allowing banks to share deposits across regions but also by allowing them to borrow short-term funds from correspondents. Country banks borrowed the most, reserve-city banks borrowed rarely, and central reserve-city banks borrowed hardly at all.

Although the interbank system helped soften seasonal demand on banks through both interbank deposits and borrowing, it did not create additional liquidity. As a result, the cash demands of country banks drained cash balances from New York City banks. Contemporaries believed that these seasonal swings contributed to bank panics and instability. This belief prompted calls for reform to create an *elastic currency* that would reduce the system's dependency on interbank relationships for seasonal liquidity (Sprague (1910)).

In response to this financial landscape, the Federal Reserve System was created in 1913 (under the Federal Reserve Act) with three primary objectives: to eliminate the concentration of bank reserves in New York City banks by establishing 12 regional reserve banks; to create an elastic currency and thereby reduce seasonal volatility; and to prevent panics (Calomiris (1994)). To achieve these goals, the Federal Reserve offered member banks access to public funds through discount windows at its 12 regional Federal Reserve Banks, requiring them to hold reserves in vault cash or as deposits at the Federal Reserve, rather than with reserve-city and central reserve-city correspondents.[5] To reduce the concentration of bank deposits in New York City, interbank deposits could no longer be used to meet reserve requirements.[6]

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into state banks and national banks and setting up a location-based three-tier system of national banks: central reserve-city banks (those located in New York City, Chicago, or St. Louis), reserve-city banks (banks in selected other large cities), and country banks (banks in all other locations). Central reserve-city banks were required to hold cash reserves equal to 25% of their deposits. Reserve-city banks were also required to hold reserves equal to 25% of their deposits, of which one-half could be deposits with a correspondent bank in a central reserve city. Country banks were required to hold reserves equal to 15% of their deposits, but they could keep three-fifths of that 15% as deposits with a correspondent bank in a reserve city and/or the central reserve city. State bank regulators subsequently passed similar laws.

[5] Even though only member banks were given access to Federal Reserve services, including the discount window, the Act made it possible to extend the discount window to nonmember banks in special circumstances with the approval of the Federal Reserve Board of Governors (see Carlson and Wheelock (2015)).

[6] The Federal Reserve Act retained for member banks the three-tier classification of central reserve city banks, reserve city banks, and country banks, but changed their reserve requirements. Member banks were required to hold 13%, 10%, and 7%, respectively, of *demand deposits* and 3% of *time deposits* with the Federal Reserve Banks. These reserve requirements were first introduced in 1913, took effect in 1914, and

The Federal Reserve Act made it compulsory for national banks to join, whereas it made it voluntary for state banks. Although the creators of the Federal Reserve System hoped to bring state banks under a more unified system of regulation and supervision, they failed to do so because most state banks chose not to join the system. By June 1915, only 17 state banks had joined. In 1917, the Federal Reserve Act was amended to encourage state banks to participate. After the amendment, membership grew slowly, eventually reaching a peak of 1,648 state member banks in 1922 (compared with 19,141 state banks that remained nonmembers, according to Committee Branch Group (1935)).[7] Even by 1929, only about 5% of state banks in the U.S. had chosen to become members, with more than 60% of all banks remaining outside the realm of the Federal Reserve System.[8]

This lack of participation had two main causes. First, the Act required members to hold reserves (in cash or with Federal Reserve), which did not pay interest. In contrast, state regulators allowed nonmembers to hold reserves in interbank deposits, which earned 2% interest (CQ Researcher (1923)). Second, member banks were subject to more stringent supervision and regulation than most nonmember banks.

The benefits of direct access to the Federal Reserve's discount window appeared insufficient to outweigh the costs of joining the system: nonmember banks could still obtain public liquidity *indirectly* through their correspondent member banks. Before 1923, the Federal Reserve System was subordinated to the Treasury's goal of supporting World War I by issuing Liberty Bonds, which allowed member banks to act as *agents* and to rediscount for nonmember banks if government bonds were used as collateral (Federal Reserve Board (1917)).[9] In 1923, the privilege given to member banks to act as agents of nonmember banks was revoked in order to encourage state banks to join.[10] This restriction, however, had limited impact on the nonmember banks' ability to access the discount window, since members simply kept using their own eligible paper to borrow from the Fed and then lent to their nonmember respondents against such collateral (CQ Researcher (1923)). This is, nonmember banks never stopped enjoying indirect access to the Fed's discount window through the interbank system even after 1923 (Virginia State Banking Division (1928) and Gruchy (1937)).

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were amended in 1917.

[7] In terms of relative size, member banks tended to be larger than nonmembers, but nonmembers still held a sizable fraction of total deposits. Appendix B.2 provides a comprehensive comparison between members and nonmembers, and their relative importance in the banking system.

[8] While there was some heterogeneity across states in terms of membership, in most states, less than 4% of state banks joined the Federal Reserve System. The exceptions were northeastern states where membership among state banks topped 30%.

[9] Between June 15th and July 15th of 1917, nonmember banks could access the discount window directly, just with the endorsement of a member bank if they used government bonds as collateral.

[10] After 1923, member banks were allowed to rediscount paper of nonmember banks as a temporary measure only during emergencies (Federal Reserve Board (1928)).

3 Empirical Evidence

In this section, we introduce our novel dataset and examine how the role and structure of the interbank system changed after the creation of the Federal Reserve, particularly for state banks that chose not to join the Fed (nonmember banks). These banks played an important role in the economy, both in number and in activity. A decade after the Fed's founding, 65% of banks remained outside the System. Despite accounting for roughly 30% of all loans in the economy, they operated without explicit access to public liquidity and outside federal regulation and supervision.

3.1 Data sources

We focus on the state of Virginia for two reasons. First, nonmember banks had a large presence in Virginia, as most *state banks* chose not to join the Federal Reserve System. By 1922, only 13 out of the state's 334 state banks had become members. Second, while some Regional Federal Reserve Banks permitted nonmember banks to access the discount window in various ways during the early 1920s, the Richmond Fed was known as a "conservative" district that adhered closely to the real bills doctrine and took a strict stand on prohibiting nonmember banks from rediscounting their commercial paper at the Fed directly (Wheelock (2004)). These banks instead obtained short-term funds from their correspondents through the instrument of "bills payable," an instrument considered relatively weak collateral. Virginia, therefore, provides a clean laboratory for studying how nonmembers changed their portfolios and interbank relations.

National banks and state member banks were regulated by the Federal Reserve Bank of Richmond, while state nonmember banks were regulated by state banking authorities. We obtain nonmember data from state bank examination reports for all state-chartered banks in Virginia. We collected reports for 1911 (before passage of the Act) and for the years 1920, 1921, and 1922 (after passage of the Act).[11] These examination reports provide rich information on the ownership structure, corporate governance, and investment portfolios (Calomiris and Carlson (2014)). For our purposes, the most valuable material concerns

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[11] State bank examination reports were introduced as part of regulators' efforts to strengthen oversight of a banking system that was expanding rapidly due to industrialization and growing commercial activity. In 1903, Virginia amended its banking law to impose stricter supervision of state banks, and in 1910, the law was amended again to require examinations of all state banks and other financial institutions. Examinations began in 1911. These reports were filed once or twice a year: examinations were conducted annually during the 1910s and became semiannual in the 1920s (Gruchy, 1937). Appendix B.1 provides additional details on these reports and includes a map of bank locations.

banks' portfolios and their relationships with correspondents.[12]

Examination reports provide detailed information on each bank's balance sheet components. On the deposit side, they record deposits *due from* other banks and deposits *due to* other banks, including the dollar amount and the name and location of each correspondent. On the borrowing side, they report *borrowed money* from other banks, again with detailed information on the lender's name and location, the loan amount, and the collateral used.[13] Banks could borrow short-term from another bank either by posting a loan or other security as collateral ("bills payable") or by selling one of their loans ("rediscounts").[14] In 1922, interbank borrowing accounted for 11% of total liabilities, with discounts and bills payable representing 2% and 9% of total liabilities, respectively.

To gauge our novel dataset, we report the average number of counterparties for the deposit and borrowing relationships of all banks in Table 1. "Banks" indicates the total number of banks in our sample, and "Respondents" indicates those that either placed a deposit and/or borrowed short-term funds. While all Virginia state nonmember banks placed interbank deposits both before and after the creation of the Fed, not all of them borrowed short-term funds. For example, in 1911, there were 206 state banks; all held deposits with correspondents, but only 79 borrowed short-term funds.

While Table 1 shows all banks with link information in our dataset, in what follows, we focus on comparing just the years 1911 (before the Fed) and 1922 (after the Fed).[15] We make this choice for two reasons. First, the results are identical when comparing 1911 with 1920 and 1921. Due to space limitations, the tables with those additional results are replicated in Appendices C.1 (for 1920) and C.2 (for 1921). Second, focusing on 1922 allows us to avoid the transition period at the Fed's foundational years.[16] We document changes in bank

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[12] A potential concern with using Examination Reports is that they may introduce spurious differences due to seasonal or other time-related factors, since examiners visited banks on different dates. We demonstrate the robustness of our findings in Appendix D.1 using Call Reports. We also show in Appendix D.2, using OCC Reports, that Virginia follows patterns representative of the United States. Although OCC Reports contain less detailed balance sheet information, they provide data for all banks at a single point in time.

[13] Examiners recorded detailed information on interbank deposits for regulatory purposes, as Virginia nonmember banks were allowed to maintain 7/12 of their required reserves in the form of interbank deposits with approved reserve agents. Examiners paid close attention to "borrowed money" because it was a good indicator of a bank's creditworthiness.

[14] Bills payable include certificates of deposit representing borrowed money, amounts due to other banks in the form of overdrafts, and notes and bills rediscounted with correspondent banks. Bills payable were typically a last resort for banks seeking additional funding after rediscounting all eligible commercial paper. Consequently, examiners viewed increases in bills payable as a sign of financial weakness. Borrowing had to remain below a bank's capital and surplus, and assets pledged as collateral could not exceed 150 percent of the amount borrowed (Virginia State Banking Division (1928)).

[15] Two additional banks in our 1922 dataset-Farmers Bank and Capeville Bank-contain only portfolio information and no linkage data.

[16] The Federal Reserve provided a three-year phase-in period for member banks to adjust to new reserve

Table 1: Interbank Deposit and Borrowing Links: 1911, 1920, 1921, 1922

Year	Relationship	Banks	Respondents	Total Links	Mean	SD
1911	Deposits	206	206	957	4.65	3.95
	Borrowing	206	79	129	0.63	1.02
1920	Deposits	292	291	1174	4.02	3.22
	Borrowing	292	169	340	1.16	1.49
1921	Deposits	331	331	1159	3.50	2.50
	Borrowing	331	203	376	1.14	1.27
1922	Deposits	317	316	1032	3.26	2.35
	Borrowing	317	167	291	0.92	1.14

balance sheets and interbank relationships along both the extensive (in terms of the number of counterparts) and intensive (in terms of the dollar amounts of the deposits and loans with a given counterpart) margins.

3.2 Changes in the Role of the Interbank System

In this section, we examine the deposit and borrowing behavior of Virginia state nonmember banks before and after the Fed's establishment. Table 2 reports the balance sheet composition of state/nonmember banks in Virginia for the years 1911 and 1922. To alleviate the concern that the balance sheet ratios are driven by new (potentially different) banks in 1922, we present ratios for all banks and for the subset of *incumbent* banks operating in both years (of the 206 banks active in 1911, 150 remained in operation in 1922). Appendix C shows that the patterns documented below also appear when comparing 1911 with 1920 and 1921, hence consistent with structural rather than idiosyncratic characteristics of 1922.

We highlight two main empirical findings:

Finding 1: After the creation of the Federal Reserve, nonmember banks reduced their holdings of liquid assets (cash and deposits in other banks): First, the share of vault cash (specie and legal tender notes) declined by 1.5 percentage points, from 4.7% of total assets in 1911 to 3.2% in 1922. Second, the share of deposits in other banks also declined by roughly 4 percentage points, from 13% of total assets to 9%. This decline in liquid assets was offset by an increase

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requirements after operations began in November 1914. Congress amended the 1913 legislation in 1917 to encourage state-bank participation. Virginia regulators reduced reserve requirements for state banks in 1915. The Fed implemented expansionary monetary policy in 1917 to support the war effort, sharply increasing short-term borrowing by nonmember banks. Finally, the Reserve Banks raised discount rates in 1920, confronting a deep recession in 1921.

in illiquid asset holdings, such as bonds and loans.

Finding 2: After the creation of the Federal Reserve, nonmember banks increased their use of short-term borrowing: Short-term borrowing increased significantly, by 1.9 percentage points, from 3.6% of total liabilities in 1911 to 5.5% in 1922.

These patterns are not driven solely by newly established banks but also reflect changes in the behavior of incumbent banks (second set of columns in Table 2). Comparing 1911 with 1920 or 1921 (in Appendices C.1 and C.2) reveals nearly identical changes in both magnitude and significance, consistent with structural rather than transitory shifts.

Taken together, these patterns are consistent with a shift from precautionary to reactive liquidity management within the interbank system after the creation of the Federal Reserve. On the liability side, banks increased interbank borrowing from their member correspondents. On the asset side, banks reduced cash holdings and interbank deposits. These changes indicate that banks relied more on short-term funds and less on their own cash and interbank deposits to manage liquidity. In effect, nonmember banks shifted away from the interbank deposit network and toward the interbank lending network.

Table 2: Balance-Sheet Ratios, Virginia State Banks, 1911 and 1922

	All Banks			Both in 1911 and 1922		
	1911	1922	Difference	1911	1922	Difference
Cash to assets	4.7	3.2	-1.5***	4.8	3.2	-1.7***
	(2.9)	(2.8)	(0.3)	(3.0)	(3.3)	(0.4)
Due-froms to assets	12.7	8.9	-3.8***	12.9	7.7	-5.2***
	(7.5)	(7.0)	(0.6)	(7.6)	(5.1)	(0.7)
Bonds to assets	3.6	6.7	3.1***	3.6	8.4	4.8***
	(7.4)	(11.3)	(0.9)	(7.6)	(11.5)	(1.1)
Loans to assets	72.3	75.1	2.8**	72.2	75.7	3.5**
	(13.3)	(14.8)	(1.3)	(13.4)	(14.1)	(1.6)
Equity to liabilities	25.1	21.9	-3.2***	24.5	19.1	-5.4***
	(9.2)	(11.1)	(0.9)	(9.2)	(7.6)	(1.0)
Deposits to liabilities	69.4	70.9	1.4	70.2	73.7	3.5**
	(13.3)	(15.5)	(1.3)	(13.5)	(13.1)	(1.5)
Due-to to liabilities	1.5	1.1	-0.4	1.8	1.4	-0.4
	(7.0)	(5.8)	(0.6)	(8.2)	(7.0)	(0.9)
Borrowing to liabilities	3.6	5.5	1.9***	3.3	5.6	2.3***
	(6.0)	(7.4)	(0.6)	(5.6)	(7.2)	(0.7)
Obs.	206	319		150	150	

3.3 Changes in the Structure of the Interbank System

In this section, we examine the change in the network structure of nonmember banks after the Fed's establishment. While the Fed's creation had a mechanical effect on the network structure of member banks, it is not immediately obvious that it would have had a similar effect for nonmembers. The Federal Reserve Act prohibited member banks from using interbank deposits to satisfy reserve requirements, but state regulators continued to allow state nonmember banks to do so. Member banks had access to the Fed's discount window, but nonmember banks did not. Hence, in principle, nonmembers may not have reacted by holding less cash or by holding less deposits in other banks. We show next that it did.

Table 1 provided a taste of how the interbank network changed. First, banks reduced the number of *correspondent banks (depository counterparties)*. The average number of correspondent relationships declined from 4.7 in 1911 to 3.3 in 1922, with a gradual reduction since 1920. This decline was driven primarily by entrants rather than incumbents. The number of correspondent relationships for incumbents remained largely unchanged (reducing slightly from 4.3 to 4). Second, banks increased short-term borrowing; one-third of all banks borrowed in 1911, compared with more than half in 1922. As before, these patterns remain robust when comparing 1911 with 1920 and 1921.

We begin by presenting a specific example that illustrates how a nonmember bank's correspondent relationships changed following the creation of the Federal Reserve. Figure 1 displays the interbank relationships of the Bank of Warm Springs in Warm Spring, Virginia. Correspondent banks that received only deposits from the Bank of Warm Springs appear in blue, while those that also extended short-term loans appear in red. The tabular component of the figure provides detailed information about these corresponding relationships and a window to our data. Columns (1), (2), and (3) list the names and locations of the correspondent banks. Columns (4) and (5) report the amount of interbank deposits due from these banks and the amount of short-term funds borrowed from them in each year.

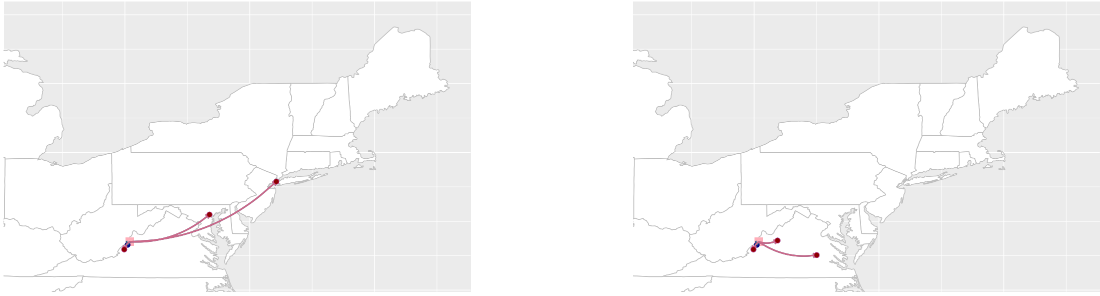
Figure 1 illustrates two major changes after the creation of the Fed. First, the system's interbank borrowing role became more important relative to its interbank deposit role. While the volume of exposures to counterparties through interbank deposits increased modestly, exposures through interbank loans increased significantly. Second, correspondent relationships became more local. In 1911, Bank of Warm Springs maintained correspondent banking relationships in New York and Baltimore, but by 1922, it had dissolved these relationships and opened new ones with banks in Richmond and Staunton, both located nearby. These changes are representative of the general patterns that characterize interbank networks before

Figure 1: Bank Network for Bank of Warm Springs

Bank of Warm Springs in Warm Springs

1911

1922



Correspondents	Town	State	Duefrom	Borrowed Money	Correspondents	Town	State	Duefrom	Borrowed Money
Chase National Bank	New York	NY	809.28	10000	Covington National Bank	Covington	VA	2562.25	21500
National Exchange Bank	Baltimore	MD	2459.28	5000	Bath County National Bank	Hot Springs	VA	1376.53	
Covington National Bank	Covington	VA	509.07	5000	Merchants National Bank	Richmond	VA	2129.64	25000
Bath County National Bank	Hot Springs	VA	237.61		National Valley Bank	Staunton	VA	1091.03	15000

and after the creation of the Federal Reserve System.[17]

We examine these changes more systematically next, highlighting several additional findings.

Finding 3: After the creation of the Fed, nonmember banks became more exposed to the largest depository correspondent: Table 3 shows that existing banks increased their exposure to the largest depository correspondent by borrowing a larger share of short-term funds from that institution. Comparing existing incumbent banks with newly established banks reveals that their borrowing concentration is similar, but new banks held substantially more interbank deposits in a single correspondent. Appendix C shows that these patterns persist when comparing 1911 with 1920 and 1921, reinforcing that the shift seems structural.

Finding 4: After the creation of the Fed, nonmember banks became more exposed to the largest short-term funding provider: From Table 4, we also find that existing banks became more exposed to the largest short-term lender, borrowing more from them but depositing less. This is a sign of decoupling between the interbank deposit and interbank borrowing networks: it was less relevant to hold deposits in banks from which they borrowed. When we compare existing banks to new banks, the size of exposures to the largest short-term lender through both interbank deposits and borrowing was larger for new banks.

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[17] In general, nonmember banks tended to connect primarily with member banks. On the interbank deposit side, relationships with member banks constituted 95% of all correspondent relationships in 1911 and 88% in 1922. On the short-term borrowing side, relationships with member banks accounted for 88% in 1911 and 85% in 1922.

Table 3: Exposures to the Largest Depository Correspondent

	Existing – Across Years			Across Banks		
	1911	1922	Difference	Existing	New	Difference
Due from to total due froms	65.9	65.2	-0.7	65.2	76.6	11.4***
	(23.3)	(21.6)	(2.6)	(21.6)	(22.9)	(2.5)
Due from to total assets	8.3	4.9	-3.4***	4.9	7.7	2.7***
	(6.2)	(3.6)	(0.6)	(3.6)	(7.0)	(0.6)
Borrowing to total borrowing	14.6	31.8	17.3***	31.8	33.1	1.3
	(32.4)	(40.2)	(4.2)	(40.2)	(43.4)	(4.7)
Borrowing to total liabilities	1.1	3.1	1.9***	3.1	3.6	0.6
	(2.8)	(4.8)	(0.4)	(4.8)	(5.6)	(0.6)
Obs.	150	150		150	169	

Table 4: Exposures to the Largest short-term loan Providers

	Existing – Across Years			Across Banks		
	1911	1922	Difference	Existing	New	Difference
Due from to total due froms	39.6	47.1	7.4	47.1	67.3	20.3***
	(34.5)	(32.4)	(5.9)	(32.4)	(33.9)	(5.1)
Due from to total assets	3.7	3.2	-0.5	3.2	4.8	1.6**
	(4.5)	(3.5)	(0.7)	(3.5)	(5.1)	(0.7)
Borrowing to total borrowing	80.9	78.7	-2.1	78.7	83.9	5.2
	(25.3)	(23.4)	(4.3)	(23.4)	(21.7)	(3.5)
Borrowing to total liabilities	6.8	6.9	0.1	6.9	8.8	1.8**
	(3.9)	(4.9)	(0.8)	(4.9)	(5.4)	(0.8)
Obs.	51	87		87	80	

In Tables 5 and 6, we document changes in the concentration of interbank relationships along both the extensive (the number of banks in a connection) and intensive (the dollar amounts involved in a connection) margins. As reported in Table 1, respondent banks typically maintained multiple correspondents with whom they placed deposits, but generally relied on only one correspondent for short-term borrowing. Hence, we examine the interbank deposit and interbank borrowing roles separately. We present three empirical findings on this front.

Finding 5: After the creation of the Fed, the interbank deposit network became less concentrated in financial centers with more deposits placed in local banks: Table 5 shows the distribution of nonmember banks' interbank deposit network. After the Fed's founding, nonmember banks shifted deposits away from New York and Baltimore and toward other country banks within Virginia. In other words, the Fed's creation reduced the need for banks to maintain correspondent ties in distant financial centers to hedge against local liquidity shocks. These changes appear at both the extensive and intensive margins and remain identical when comparing 1911 with 1920 and 1921. As shown in Appendix B.2, they were mostly driven by new banks.

Table 5: Geographic Interbank Deposit Network, All Banks

Due from Deposits in:	Extensive Margin (Links)			Intensive Margin (Amount)		
	1911	1922	Difference	1911	1922	Difference
New York City	19.7	12.8	-6.9***	10.8	7.0	-3.8***
	(18.3)	(16.6)	(1.5)	(16.2)	(13.9)	(1.3)
Baltimore	9.7	7.0	-2.7*	10.7	7.0	-3.7*
	(18.3)	(16.5)	(1.5)	(23.9)	(19.7)	(1.9)
Washington, DC	2.2	1.8	-0.4	1.8	1.6	-0.2
	(7.8)	(9.8)	(0.8)	(7.4)	(10.8)	(0.9)
Richmond	21.9	22.2	0.4	29.3	27.4	-1.9
	(21.1)	(27.8)	(2.3)	(32.7)	(34.7)	(3.0)
Reserve Cities in Other States	2.4	3.5	1.1	2.6	4.0	1.5
	(7.1)	(13.6)	(1.0)	(8.5)	(16.7)	(1.3)
Country Banks in VA	41.3	50.0	8.7***	40.3	51.0	10.7***
	(28.2)	(34.6)	(2.9)	(37.1)	(40.7)	(3.5)
Country Banks in Other States	2.9	2.8	-0.1	3.4	1.7	-1.7
	(11.0)	(10.3)	(0.9)	(15.3)	(9.4)	(1.1)
Obs.	206	316		206	316	

Finding 6: After the creation of the Fed, the interbank borrowing network became less concentrated in financial centers with more local correspondents - though to a lesser extent than the interbank deposit network: Table 6 shows the structure of the interbank borrowing network. After the Fed's establishment, the concentration of short-term borrowing from correspondents in financial centers also declined, although the shift toward local correspondents was smaller than on the deposit side. Before the Fed, 23% of nonmembers borrowed from other county banks in Virginia, fewer than those who borrowed from banks in Richmond. After the Fed's creation, nearly 50% of them borrowed from county banks, while other cities, particularly Richmond, saw a decline. These changes appear at both the extensive and intensive margins and remain robust when compared with 1920 and 1921. As shown in Appendix B.2, they were also mostly driven by new banks.

Finding 7: After the creation of the Fed, the distance between respondents and correspondents of the interbank deposit network declined, but the distance between banks of the interbank borrowing network remained unchanged: We compute the distance in miles between respondent

Table 6: Geographic Interbank Borrowing Network, All Banks

Short-term Borrowing from:	Extensive Margin (Links)			Intensive Margin (Amount)		
	1911	1922	Difference	1911	1922	Difference
New York City	9.6	8.9	-0.7	8.7	8.8	0.1
	(24.5)	(22.5)	(3.2)	(23.7)	(23.0)	(3.2)
Baltimore	9.7	7.1	-2.7	9.8	6.8	-2.9
	(27.4)	(23.2)	(3.4)	(27.1)	(23.2)	(3.3)
Washington, DC	0.6	1.2	0.6	0.6	1.2	0.6
	(4.2)	(10.9)	(1.3)	(3.8)	(10.9)	(1.3)
Richmond	30.4	20.7	-9.8*	31.5	21.5	-10.0*
	(40.3)	(35.2)	(5.1)	(41.7)	(36.4)	(5.2)
Reserve Cities in Other States	2.6	4.3	1.8	2.6	4.6	2.0
	(13.2)	(17.6)	(2.2)	(13.4)	(18.7)	(2.3)
Country Banks in VA	23.8	46.3	22.5***	22.0	46.2	24.2***
	(38.8)	(43.8)	(5.8)	(37.6)	(44.8)	(5.8)
Country Banks in Other States	23.2	11.6	-11.6***	21.4	10.3	-11.0***
	(38.5)	(25.6)	(4.2)	(37.9)	(25.4)	(4.1)
Obs.	78	167		80	168	

and correspondent banks. Table 7 reports both the longest and the average distance for each bank's interbank deposit and borrowing relationships. Distances in the interbank deposit network were initially larger than those in the borrowing network. After the Fed's founding, these distances shortened in the interbank deposit network but not in the interbank borrowing network.[18] This shift of correspondent relationships away from New York and toward local banks transformed a *national core-periphery structure* based in New York City into a *regional core-periphery structure* based in reserve cities.[19]

The changes we have documented regarding the role of the interbank system are consistent with its evolving structure. As shown in Carlson and Wheelock (2018a), New York City banks provided private liquidity arrangements against regional liquidity shocks and smoothed interregional flows by pooling interbank deposits from different regions (*interregional insurance*). In contrast, when they could not withdraw interbank deposits, banks tended to borrow locally (Redenius and Weiman (2011)). After the Fed's creation, banks relied more on short-term

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[18] These findings are consistent with Carlson and Wheelock (2018a), who show that New York City banks provided private liquidity insurance against regional liquidity shocks and smoothed interregional flows by pooling reserves from different regions (Gilbert, 1983; James and Weiman, 2010), and with Jaremski and Wheelock (2020), who document the concentration of correspondent linkages (at the extensive margin) in cities hosting regional Federal Reserve Banks.

[19] This pattern is also consistent with Odell and Weiman (1998) and Jaremski and Wheelock (2020), who show that after the Fed's founding, banks increasingly established correspondent ties with nearby cities hosting Federal Reserve offices.

Table 7: Distance between Respondent and Correspondent Banks, All Banks

Distances (in miles):	Interbank deposits			Interbank borrowing		
	1911	1922	Difference	1911	1922	Difference
Longest Distance	292.7	213.9	-78.8**	148.8	165.8	17.0
	(150.8)	(422.0)	(30.6)	(141.9)	(567.6)	(67.4)
Mean Distance	131.8	114.4	-17.5	105.8	132.5	26.7
	(73.6)	(404.4)	(28.5)	(101.8)	(562.3)	(66.4)
Total Distance	629.2	367.6	-261.7***	242.7	223.0	-5.2
	(678.8)	(556.5)	(54.4)	(270.8)	(590.3)	(69.1)
Obs.	206	316		73	164	

borrowing and less on interbank deposits to manage liquidity. Because banks could borrow from other nearby member banks, their borrowing relationships became more local. And because they no longer needed to rely on interbank deposits held in New York City to manage liquidity, their interbank deposit relationships also became more local.

To summarize, the creation of the Federal Reserve altered both the role and the structure of the interbank system for banks operating outside the Federal Reserve System along several dimensions. In the theoretical section, we develop a model that shows how the insurance role of an interbank system can generate these empirical patterns and yield additional testable implications. We then use the model to derive implications for how the Fed may have weighed the pros and cons of public liquidity and reserve requirements, accounting for their effects on investments and financial stability.

4 Nonmember Banks' Reliance on Public Liquidity

4.1 1920-21 Recession

In normal times, the interbank system played a crucial role in managing pronounced seasonal demand for money and credit, which peaked in spring and autumn as farmers financed planting and harvesting (Barsky and Miron, 1989; Davis et al., 2009; Kemmerer, 1910). These seasonal pressures were especially acute in the South, where cotton production dominated agricultural activity. Farmers steadily accumulated short-term debts from February through June using their credit lines and repaid these obligations only after the cotton harvest in late August through early November. As a result, outstanding loans at rural banks reached their annual peak in July and August. To bridge these seasonal funding gaps, rural banks relied heavily on correspondents in financial centers, drawing on both interbank deposits and short-term borrowing.

The 1920-21 recession constituted the first major distress episode after the Federal Reserve was established, and put to test the new banking system. Although brief, the 1920–21 recession was exceptionally severe. The U.S. economy experienced a four-quarter decline in GNP of 16.5%, followed by a four-quarter rebound of 12.4%. Carlson (2025) provides a comprehensive discussion of the downturn and the Fed's role during this episode. Wholesale prices for farm products fell by nearly 37% (Smiley (2004)), and farm incomes declined by roughly 60% from their 1919 peak to their 1921 trough, reflecting the profound hardship faced by farmers (Rajan and Ramcharan (2015)). This collapse in agricultural prices stemmed from shrinking post-war demand, the recovery of European agricultural production, the termination of wartime price supports, and restrictive monetary policy. Rural economies suffered acutely, placing significant strain on banks concentrated in agricultural regions.

These adverse conditions were especially pronounced in the southern states, including Virginia, where cotton prices fell by 70%, many rural state nonmember banks held undiversified portfolios - dominated by cotton-related loans - and lacked direct access to the Federal Reserve's discount window. Bank suspensions rose sharply—from 167 in 1920 to 505 in 1921—but no banking panics occurred, despite earlier recessions of similar magnitude having produced major panics (Gorton, 1988). Tallman and White (2020) argue that this stability was due in part to the liquidity support provided by Federal Reserve Banks to member institutions in agricultural and rural districts, which enabled banks to roll over loans and avoid fire sales of cotton-related collateral at depressed prices. What prevented large panics from ensuing among nonmembers?

4.2 The Role of Members to Sustain Nonmembers

Member banks were crucial for the survival of rural nonmember banks during the stressful years of 1920 and 1921. Carlson (2025) shows that the Federal Reserve's response to the crisis relied heavily on the structure of the correspondent banking system. As agricultural prices collapsed and rural nonmember banks came under acute strain, Reserve Banks directed liquidity to member institutions that served as correspondents for large networks of smaller banks (Carlson (2025), p. 2). This strategy created an intentional pass-through mechanism: by stabilizing these member-bank hubs, the Fed ensured that correspondent credit lines and interbank balances—vital funding sources for nonmember country banks—remained intact (Carlson (2025), pp. 45–46). His analysis therefore supports the interpretation that targeted liquidity to the member-bank core was an effective way to stabilize the broader nonmember periphery during the most severe phase of the recession. Besides this effect being intentional or not, the fact is that it may have consolidated nonmembers' beliefs of indirect access to the Fed's discount windows.

We now measure the extent of this support in Virginia. Using information on 1) members' loans to nonmembers and 2) members' borrowings from the Federal Reserve Bank of Richmond, we compute a "pass-through rate" by member bank – the amount of short-term loans that a member granted to nonmembers as a fraction of the amount such member obtained from the discount window provided by the Federal Reserve Bank of Richmond.[20]

Figure 2 plots this pass-through rate for each Virginia member bank (conditional on observing their borrowing from the Richmond Fed). On average, member banks lent 20% of their discount window loans to their nonmember respondents in 1920, 40% in 1921, and 20% again in 1922. Member banks were therefore substantially more instrumental in transmitting Federal Reserve liquidity to nonmembers at the peak of the recession. This sharp increase in pass-through was driven not by banks in Richmond or Norfolk but by member banks located in smaller cities, consistent with (1) county banks facing the most acute liquidity needs and (2) the interbank network becoming more locally oriented after the creation of the Fed.

While previous studies emphasize the importance of correspondents in financial centers (central reserve and reserve cities) for providing liquidity to their respondents, we find that local correspondents—member banks in small cities and counties, located closer to rural nonmembers—also played a significant role in passing through discount-window liquidity, especially during the recession. Pass-through rates during 1920–1921 were lower in Richmond (16% on average, compared with 23% in 1922), similar in Norfolk (around 21% both during the recession and in 1922), but substantially higher among rural member banks (23% on average during 1920–1921 compared with 13% in 1922). These patterns indicate that local correspondents stepped up during the crisis, becoming key conduits of Federal Reserve liquidity to nonmember banks.

Lastly, we observe substantial variation in pass-through rates across member banks. Some banks passed through less than 10% of their discount-window borrowings to nonmembers, while others passed through more than 50%. There is also considerable heterogeneity in the number of nonmembers each member bank served. Member banks in Richmond and

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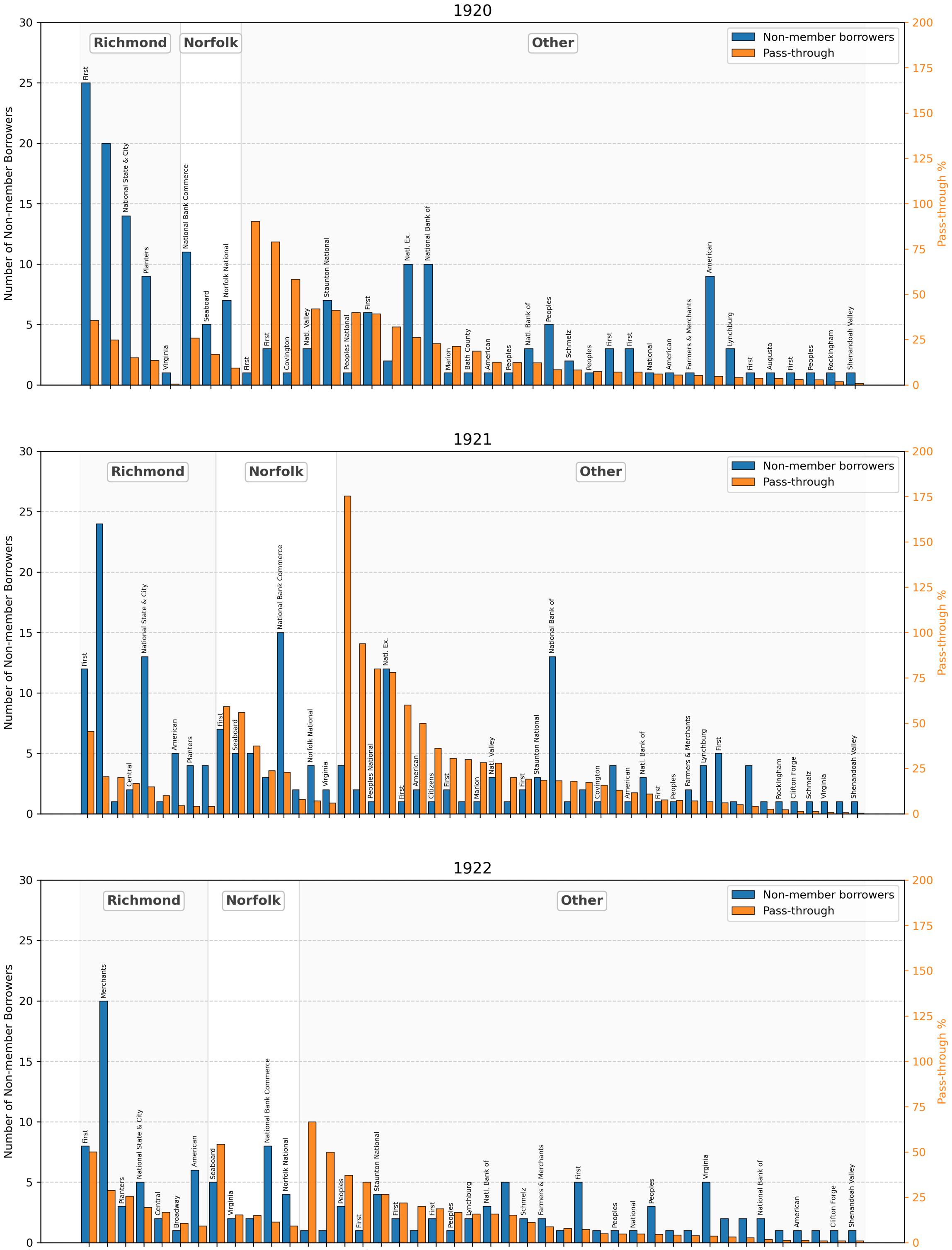
[20] We focus on short-term funding providers in Virginia. First, correspondents in Virginia supplied a large proportion of short-term funds, accounting for over 65% of total short-term loans. Second, interbank lending was local in Virginia. Unlike other correspondents in New York, Richmond banks supplied short-term loans mostly to other banks in Virginia. Since New York City banks lent short-term loans to banks in other regions, and we do not know the amount of these loans provided to nonmember banks in other areas, we cannot calculate pass-through rates from New York City member banks to nonmember banks.

Figure 2: Passthrough



Notes: The left vertical axis shows the number of nonmember borrowers of each member bank. The right vertical axis shows the pass-through figures (in percentage of total borrowing from the discount window).

Norfolk maintained the largest networks—an average of eight nonmember correspondents in Richmond and five in Norfolk—whereas rural correspondents served, on average, only two.

The anatomy of pass-through during distress, combined with the evidence that the interbank network became more locally oriented after the Fed's creation, suggests an elevated role for local correspondents in channeling liquidity when the banking system came under strain. In effect, liquidity provision became more decentralized, with smaller, locally connected member banks stepping in as key conduits during the recession.

5 Model

Motivated by the documented changes in the role and structure of the interbank system after the creation of the Federal Reserve, we construct a model of portfolio choices and endogenous network formation that accommodates these findings in response to public liquidity provision. The model is designed to organize the main empirical patterns. We begin with the premise that, in the absence of public liquidity, the interbank system provides banks with *insurance through diversification* by holding deposits with other banks. Once member banks gain access to the discount window, and nonmembers can obtain liquidity indirectly through member correspondents, the value of this private insurance declines. This mechanism rationalizes the joint movements we document in both portfolios and network structure. We then use the model in a quantitative exercise to assess whether the magnitudes required by the mechanism are plausible and to evaluate the trade-off between public and private liquidity.

We begin with an environment containing only two banks - a member and a nonmember - and analyze how the introduction of public liquidity affects their joint portfolios. We then expand the environment to include additional banks to study how this affects the structure of the interbank network. Our analysis proceeds in two steps. First, we characterize the benchmark environment without public liquidity. Next, we introduce public liquidity and show how it alters bank portfolios and the organization of the interbank system.

5.1 Environment

The economy consists of two banks, x (nonmember bank) and y (member bank in a reserve city). Bank x receives exogenous D_x household deposits (at a rate normalized to 0). It can invest in a project yielding a net rate of return $r_x > 0$, place an interbank deposit L with bank y at a rate $r < r_x$, or hold cash. Bank y receives exogenous D_y household deposits, L interbank deposits from bank x, and has access to a project yielding a net rate of return

$r_y > r > 0$.[21] Projects are safe and can be liquidated at any time for their full principal, but only in their entirety (*no partial liquidation*).[22] We model the banking system in partial equilibrium, abstracting from how it affects investment opportunities in the broader economy, because our focus is on how portfolios and connections adjust when public liquidity becomes available.[23]

Because our focus is on interbank relations, we treat the household side as exogenous: households just generate withdrawal shocks that create uncertain liquidity needs for banks. For this reason, in what follows we assume $D_y = 0$. We relax this assumption in the quantitative exercise to introduce uncertainty in nonmember banks' access to public liquidity.

Reserves and investments After investments are made, some households may withdraw their deposits from bank x before the projects mature, generating a *liquidity shock*. Because projects are indivisible and can only be liquidated in full, bank x prefers to maintain reserves to cover relatively small withdrawals. As discussed above, bank x can do so in two ways: by holding cash or by placing interbank deposits with bank y. Bank y chooses how much of its deposits to invest and how much to hold cash, subject to a reserve requirement that forces it to maintain a fraction ϕ of liabilities in cash.

Let Φ_x denote bank x's cash holdings, and L bank x's interbank deposits at bank y. Bank x's investment is therefore $I_x = D_x - \Phi_x - L$. Similarly, let Φ_y denote bank y's cash holdings, with the reserve requirement constraint $\Phi_y \geq \phi L$. Bank y's investment is $I_y = L - \Phi_y$. We refer to I_x and I_y as *investments*, Φ_x and Φ_y as *cash reserves*, and L as the *interbank deposits*. We treat ϕ as exogenous here; in the next section, we allow a planner to choose the optimal combination of public liquidity provision m and private liquidity regulation ϕ.

Figure 3 summarizes transactions and obligations in the absence of liquidity shocks.

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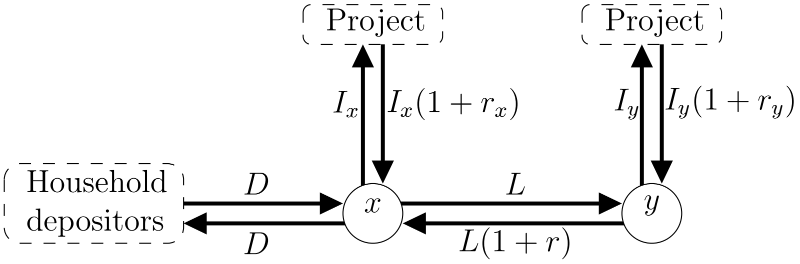
[21] We assume banks capture all surplus from channeling funds from households to firms, so deposit and lending rates are exogenous and determined by the outside opportunity of households and the net present value of firms' projects. We also assume that nonmember and member banks share this surplus, with nonmembers having bargaining power r/r_y, which is exogenous.

[22] Assuming safe, fully liquidating projects avoids multiple payment states and default risk. Indivisibility still captures the costs of liquidity shocks. Although projects are safe, the model still captures the risk-taking implications of public liquidity: banks choose the size of the project rather than its default probability, and larger projects increase the likelihood of forced liquidation. In this sense, a larger project is analogous to a riskier one.

[23] General equilibrium forces affecting interest rates likely influence magnitudes but not directions. Empirical evidence from Cox (1967) and James (2015) shows that interest rates - especially deposit rates - were remarkably stable. During the National Banking Era, reserve city banks paid 2% (and no more than 2%) interest on interbank deposits, a rate that did not change after the Fed was created.

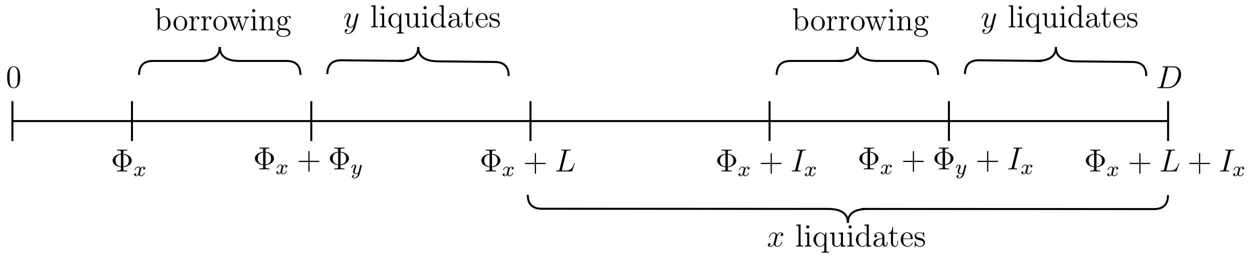
Figure 3: Transactions absent Liquidity Shocks



Liquidity shocks Liquidity shocks arise when some households withdraw their deposits before projects mature. Such withdrawals disrupt the flow of funds depicted in Figure 3. Because projects cannot be partially liquidated, depositors can always recover D regardless of shocks, allowing us to focus on liquidity crises rather than solvency crises while still maintaining the inefficiency associated with forced liquidations.

Let ζ_x denote household early withdrawals (before the project matures). With probability $1-\alpha_x$, no early withdrawal occurs and $\zeta_x = 0$. With probability α_x,withdrawals are drawn from a continuous cumulative distribution $\zeta_x \sim S(\cdot)$ on $[0, D]$. Depending on the size of the shock and the size of investments, different scenarios may arise. Figure 4 schematically illustrates these scenarios for the case in which bank x prefers to withdraw its interbank deposits from bank y before liquidating its own project. We derive the conditions that guarantee this pecking order later in the section.

Figure 4: Size of the Liquidity Shock and Transactions



Based on these regions, define the probability that bank x's project is not liquidated by

$$\Gamma \equiv (1-\alpha_x) + \alpha_x S(\Phi_x + L)\,,$$

and the probability that bank y's project is not liquidated by

$$\Delta \equiv (1-\alpha_x) + \alpha_x \left[S(\Phi_x+\Phi_y) + (S[\Phi_x+\Phi_y+I_x] - S[\Phi_x+L])\right].$$

In this setting, bank y's project is liquidated only when withdrawal shocks to bank x trigger interbank deposit withdrawals, forcing bank y to liquidate its project to repay. We therefore define the probability of *upstream contagion* simply by $1-\Delta$. In the quantitative setting - where bank y also faces its own withdrawal shocks - its project may be liquidated due to its own needs, which can in turn trigger liquidation of bank x's investment, generating *downstream contagion.*

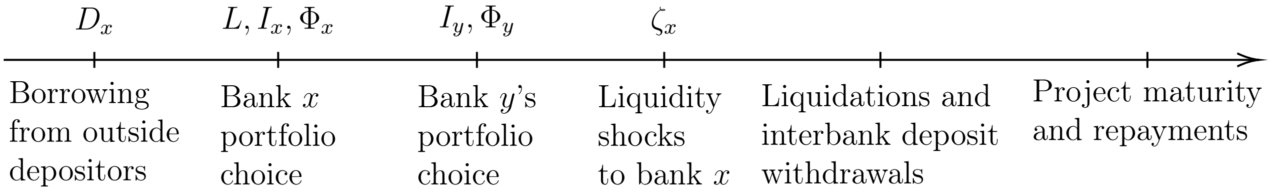
Based on these probabilities, bank x's and bank y's expected profits are, respectively,

$$\Pi_x = \Gamma I_x r_x + \Delta L r, \tag{1}$$

$$\Pi_y = \Delta \left(I_y r_y - L r \right). \tag{2}$$

Timing Given the expected profits, bank x chooses investment I_x and interbank deposits L, which jointly determine its cash reserves Φ_x. Bank y chooses its investment I_y, which determines its cash reserves Φ_y, subject to reserve requirements $\Phi_y \geq \phi L$. After these choices are made, withdrawal shocks materialize for bank x. This timeline is depicted in Figure 5.

Figure 5: Timeline of events



5.2 Equilibrium

We solve for the subgame perfect Nash equilibrium in the baseline environment ($m = 0$). Bank x chooses I_x and L to maximize Π_x subject to $I_x, L \geq 0$ and $I_x + L \leq D$. Bank y then chooses $I_y \in [0, (1-\phi)L]$ to maximize Π_y. The solution depends on the structure of liquidity shocks. In what follows, we focus on parameter values and shock realizations that ensure two features: (i) the reserve requirements bind - so bank y holds cash for $\Phi_y = \phi L$ - and (ii) bank x follows a natural pecking order in insuring against liquidity shocks, relying first on interbank deposits and then on cash. The conditions that satisfy the second feature are simply $r > 0$. The first feature is satisfied according to the following Lemma.

Lemma 1. *Bank y's reserve requirement binds on path, so that* $\Phi_y = \phi L$*, if for all feasible* (I_x, L, Φ_x) *with* $\Phi_y \in [\phi L, L]$*,*

$$r_y \Delta > \big((L - \Phi_y) r_y - Lr\big)\, \partial_{\Phi_y} \Delta.$$

Intuitively, along the bank y's feasible set, the private return from investing an additional unit in I_y dominates the benefits of holding that unit as cash, thereby increasing the project's survival probability. Whether this condition holds depends on the structure of liquidity shocks, which determines the shape of the probability Δ for bank y's project.

Focusing on shock structures that satisfy these conditions, we now characterize the environments that generate a pecking order in bank x's optimal portfolio.

Proposition 1. *Equilibrium Portfolios Without Public Liquidity Provision* $(m = 0)$*.*

Assume Lemma 1 and $S \in C^1([0, D])$ *with density* $s = S'$*. Let* (I_x^0, Φ_x^0) *solve bank x's problem with* $L = 0$*, and let* (I_x^L, L_x^L) *solve the same problem with* $\Phi_x = 0$ *(so* $I_x^L = D - L_x^L$*). Define directional net marginal values*

$$\mathcal{M}_L(\alpha_x) := \frac{d}{d\varepsilon} \Pi_x(I_x^0 - \varepsilon, \varepsilon, \Phi_x^0)\bigg|_{\varepsilon=0^+} = r - r_x\big[(1-\alpha_x) + \alpha_x S(\Phi_x^0)\big] + \alpha_x r_x I_x^0 s(\Phi_x^0),$$

$$\mathcal{M}_\Phi(\alpha_x) := \frac{d}{d\varepsilon} \Pi_x(I_x^L - \varepsilon, L_x^L, \varepsilon)\bigg|_{\varepsilon=0^+} = r_x\big[\alpha_x I_x^L s(L_x^L) - (1-\alpha_x) - \alpha_x S(L_x^L)\big] + \alpha_x r L_x^L \big[s(\phi L_x^L) - s(L_x^L)\big].$$

Suppose:

(i) Π_x *is strictly concave on* $\{(I_x, L, \Phi_x) : I_x, L, \Phi_x \geq 0,\ I_x + L + \Phi_x \leq D\}$*;*

(ii) $\mathcal{M}_L(\alpha_x)$ *is continuous and crosses zero once;*

(iii) $\mathcal{M}_\Phi(\alpha_x)$ *is continuous and crosses zero once, at a strictly larger* α_x*.*

Then there exist cutoffs

$$0 < \alpha_L < \alpha_\Phi < 1$$

such that

$$\alpha_x < \alpha_L :\ (I_x, L, \Phi_x) = (D, 0, 0),$$

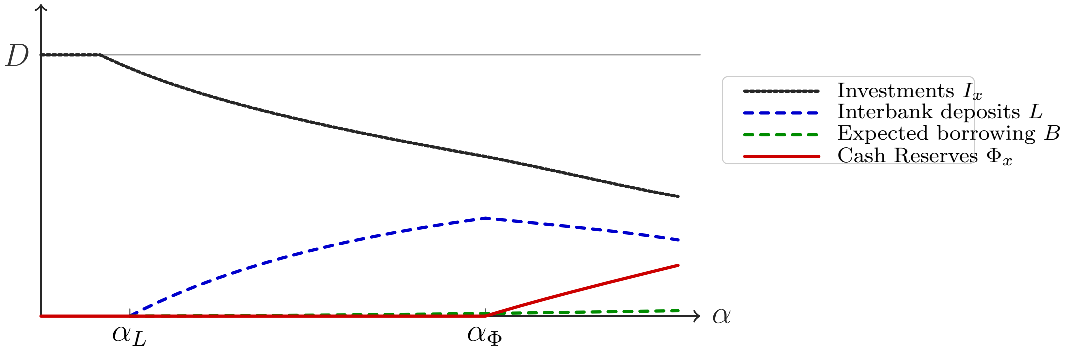
$$\alpha_L < \alpha_x < \alpha_\Phi :\ L > 0,\ \Phi_x = 0,$$

$$\alpha_x > \alpha_\Phi :\ L > 0,\ \Phi_x > 0.$$

Hence, portfolios follow the pecking order: own project, then interbank deposits, then cash.

This proposition provides a sufficient-condition characterization of a pecking order in portfolio choices. Under the stated single-crossing conditions, a decline in withdrawal risk leads bank x to reduce cash holdings first and only then reduce interbank deposits. Figure 6 illustrates an example of the resulting portfolio allocation as a function of withdrawal risk (parameterized by α, the probability that there is a withdrawal), with thresholds α_L and α_Φ corresponding to those in Proposition 1. The line B denotes expected short-term borrowing Φ_y and it is given by $B = \alpha_x(S(\Phi_x + \Phi_y) - S(\Phi_x) + S(\Phi_x + I_x + \Phi_y) - S(\Phi_x + I_x))$, from the regions of borrowing in Figure 4; we include it to show how borrowing reliance comoves with L and Φ_x.

Figure 6: Investments, Interbank Deposits, Short-Term Borrowing, and Cash Reserves



Next, we assume that public liquidity m is available to bank x to absorb liquidity shocks. This is equivalent to replacing the original shock ζ'_x with the effective shock $\zeta'_x \equiv \max\{\zeta_x - m, 0\}$. This constitutes the same characterization of the Proposition 1 with a first-order stochastic dominance decline in the distribution of effective shocks as m increases. Formally,

$$\mathbb{P}(\zeta' \leq z) = S(m + z).$$

We can rewrite bank x's ex-ante profits, given m, as

$$\Pi_{x,m} = \Gamma_m I_x r_x + \Delta_m L r, \tag{3}$$

where

$$\Gamma_m = (1 - \alpha_x) + \alpha_x S(\Phi_x + L + m)\,,$$

$$\Delta_m = (1 - \alpha_x) + \alpha_x \left[S(\Phi_x + \Phi_y + m) + (S[\Phi_x + \Phi_y + I_x + m] - S[\Phi_x + L + m])\right].$$

The following proposition extends Proposition 1 with public liquidity provision.

Proposition 2. *Equilibrium Portfolios With Public Liquidity Provision.*

Fix $m \in [0, D]$ and define shifted primitives

$$S_m(z) := S(z + m), \qquad s_m(z) := s(z + m).$$

If assumptions (i)–(iii) in Proposition 1 hold with (S, s) replaced by (S_m, s_m), then there exist cutoffs

$$0 < \alpha_L(m) < \alpha_\Phi(m) < 1$$

such that

$$\alpha_x < \alpha_L(m): \ (I_x, L, \Phi_x) = (D, 0, 0),$$

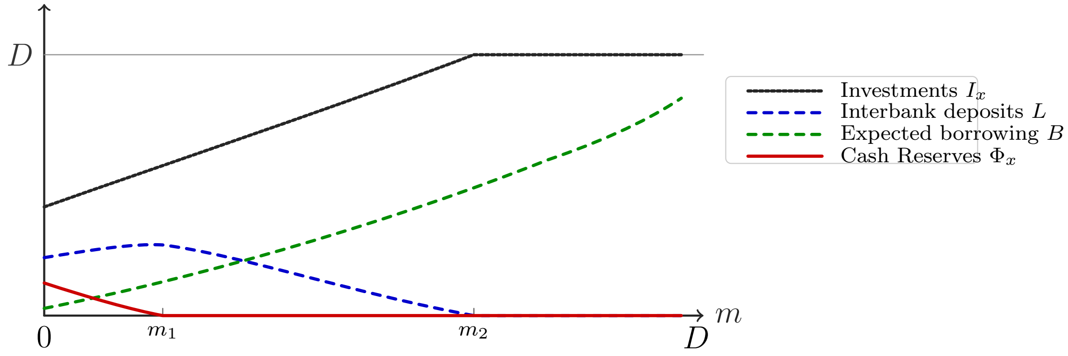
$$\alpha_L(m) < \alpha_x < \alpha_\Phi(m): \ L > 0, \ \Phi_x = 0,$$

$$\alpha_x > \alpha_\Phi(m): \ L > 0, \ \Phi_x > 0.$$

Therefore, the pecking order survives with public liquidity, with effective shock distribution S_m (equivalently, shocks $\zeta'_x = (\zeta_x - m)_+$).

Figure 7 shows the portfolio allocation as a function of public liquidity m for a fixed high-α_x (a region in which bank x holds positive cash), using the same parameters as in Figure 6. As m increases, banks' effective exposure to liquidity shocks falls when choosing their portfolios, and bank x correspondingly reduces its private liquidity - cash first and then interbank deposits - while increasing expected short-term borrowing.

Figure 7: Investments, Interbank Deposits, Short-Term Borrowing, and Cash Reserves



The next Corollary shows that strong substitutability between cash and interbank deposits is a sufficient condition for the pecking order. This requirement primarily restricts the structure of shocks, since it governs how the marginal value of cash compares with that of interbank deposits. We show that this condition is satisfied not only when shocks follow a uniform distribution, but also when they follow more flexible families, such as the Gamma distribution for appropriate parameter values.

Corollary 1. *(Primitive sufficient condition via strong substitutability).*

Under Proposition 1, define (along $\Phi_x = 0$, $I_x = D - L$*)*

$$\mathcal{M}_\Phi(\alpha_x; L) = r_x[\alpha_x(D-L)s(L) - (1-\alpha_x) - \alpha_x S(L)] + \alpha_x r L[s(\phi L) - s(L)]\,.$$

Then

$$\partial_L \mathcal{M}_\Phi(\alpha_x; L) = \alpha_x\, \Xi(L),$$

where

$$\Xi(L) := r_x[(D-L)s'(L) - 2s(L)] + r\big[s(\phi L) - s(L) + L\big(\phi s'(\phi L) - s'(L)\big)\big]\,.$$

If $\Xi(L) < 0$ *for all* $L \in (0, D)$*, cash and deposits are strong substitutes (a larger* L *lowers the net marginal value of cash), so cash enters after deposits. With interior endpoint signs for both margins, interior cutoffs satisfy*

$$0 < \alpha_L < \alpha_\Phi < 1.$$

For a uniform distribution, this is always the case, since on $[0, D]$

$$S(z) = z/D \qquad s(z) = \frac{1}{D} \qquad s'(z) = 0$$

For truncated Gamma shocks on $[0, D]$,

$$S(z) = \frac{F_\Gamma(z; k, \theta)}{F_\Gamma(D; k, \theta)}, \qquad s_{k,\theta}(z) = \frac{z^{k-1}e^{-z/\theta}}{\theta^k \Gamma(k)\, F_\Gamma(D; k, \theta)},, \qquad s'_{k,\theta}(z) = s_{k,\theta}(z)\left(\frac{k-1}{z} - \frac{1}{\theta}\right).$$

A sufficient condition on (k, θ) *is,* $\Xi_{k,\theta}(L) < 0$ *for all* L*, which can be guaranteed for* $0 < k \leq 1$ *(decreasing near-zero density) and* θ *low enough. .*

Remark on endogenous liabilities: We assume that bank x obtains funds exogenously from households and does not raise any equity. Endogenizing D_x would require bank x to internalize the risk of early withdrawals when choosing its liability structure, and would therefore call for a richer framework to determine its optimal debt/equity ratio. Regardless of the specific modeling environment, however, bank x is less willing to raise household deposits when it faces a high level of withdrawal risk (high α_x). Conversely, its incentives to raise deposits increase with m, since public liquidity reduces the effective liquidity risk associated with it. These comparative statics would reinforce the portfolio patterns of Findings 1 and 2.

Remark on adding possible counterparties: The investment decisions of bank x in response to an increase in α_x extend naturally to the case in which it can place deposits across multiple depository institutions y_1, y_2,...,y_N with project returns ordered by $r_{y1} > r_{y2} > ... > r_{yN}$. If bargaining power is constant, as assumed so far, as α_x rises, bank x first expands deposits in its preferred counterparty bank y and then, once that opportunity is exhausted, moves to the next best option, eventually turning to cash. With many potential counterparties, bank x would sequentially place deposits in bank y_2, then bank y_3, and so on. An increase in public liquidity m reverses this pecking order. As m grows, bank x unwinds positions in lower-ranked counterparties and concentrates its activity with its primary counterparty, y_1, both for placing deposits and for short-term borrowing. This pattern follows directly from public liquidity, which reduces the need for diversification across counterparties, consistent with Findings 3 and 4.

This two-bank exercise highlights how the introduction of public liquidity changes the role of interbank relationships for nonmember banks. Even though they cannot access the central bank directly, they become less inclined to diversify their portfolios and counterparties once they obtain liquidity indirectly by borrowing from their correspondents. Next, we extend the analysis by introducing additional counterparties to study how the structure of the interbank network responds to public liquidity.

5.3 Networks

In this section, we show that public liquidity provision induces nonmember banks to reallocate their interbank relations to less costly counterparties, such as those geographically closer. This rationalizes the shift we document from central reserve cities toward regional reserve cities and local correspondents. In a sense, public insurance not only crowds out private insurance, but also cross-regional insurance.

To illustrate this mechanism, we extend the analysis to four banks organized into two pairs. Banks x_1 and y_1 interact as in the baseline model, and the same is true for banks x_2 and y_2. As before, banks x_1 and x_2 hold household deposits and projects, while banks y_1 and y_2 receive interbank deposits received from x_1 and x_2, and also operate projects. We refer to $\{x_1, x_2\}$ *the periphery* and $\{y_1, y_2\}$ *the core.* We now impose the following assumption on the withdrawal shocks faced by peripheral banks.

Assumption 1 (Liquidity Shocks for Two Banks)**.** *With probability $\bar{\alpha} = \frac{\alpha_x}{2}$, banks x_1 and x_2 each experience a liquidity shock ζ drawn from the same distribution as in the previous section. With probability $1 - 2\bar{\alpha}$, no bank experiences a liquidity shock and $\zeta_1 = \zeta_2 = 0$.*

With liquidity coinsurance at the core, the ex-ante profits of each bank x_i are

$$\Pi_{x_i} = \Gamma_i I_{x_i} r_x + \Delta_i L_i r,$$

where Γ_i and Δ_i are defined as in (3), and effective liquidity is given by the sum of public liquidity m and private liquidity ϕL_j provided by the other core bank. Sharing a common core with other banks is therefore equivalent to bank x having access to a larger liquidity buffer when shocks occur. This observation leads directly to the next proposition.

Proposition 3. *Core Co-Insurance and Interbank Deposits*

Liquidity coinsurance at the core reduces equilibrium interbank deposits by peripheral banks relative to the case without coinsurance, holding public liquidity m fixed.

This simple setting shows that, in the absence of public liquidity, core banks coinsure one another by effectively forming a clearinghouse - much like the large New York banks historically did before the Federal Reserve Act.

Now assume that periphery banks located in different regions can choose their correspondents from two groups: banks with stronger coinsurance possibilities but located farther away (e.g., New York) and banks with weaker coinsurance possibilities but located closer (e.g., regional reserve cities). This extension allows us to study how the Fed's liquidity provision m reshapes the network structure. As public liquidity becomes available, links shift from the distant core (New York City) to the closer core (regional reserve cities), crowding out the private insurance that the interbank system previously provided. This result is summarized below.

Proposition 4. *Network Geographic Concentration*

There exists m_c such that for $m < m_c$, banks connect to core banks, while for $m > m_c$, banks connect to local reserve cities.

The creation of the Federal Reserve System produced a more decentralized interbank network with a greater role for regional banking centers, consistent with Findings 5, 6, and 7.

5.4 Testable implications

Our simple model helps explain the changes we documented in the data after the creation of the Federal Reserve. The main mechanism is a shift from relying on private insurance through diversification to relying on insurance via indirect access to public liquidity, made possible by borrowing from member banks. Public liquidity encouraged nonmember banks to increase interbank borrowing from their member correspondents, hold fewer liquid assets and deposits with other banks, invest more heavily in illiquid assets, and seek closer counterparties.

This simple model also delivers additional testable implications. For instance, the model predicts that banks that rely more on borrowing would change their portfolios and connections more. We then compare the portfolio structure of banks by borrowing status. We divide the 150 incumbent banks existing in 1911 and 1922 into four groups based on their borrowing status in 1922: (1) banks that did not borrow in either year, (2) banks that borrowed in both years, (3) banks that borrowed only in 1911, and (4) banks that borrowed only in 1922. Table 8 reports balance sheet ratios for each group, and presents mean differences using Dunnett's method. On the asset side, banks that borrowed in 1911 and 1922, or even only in 1922, held fewer liquid assets (cash and interbank deposits) and increased their illiquid assets (lending). On the liability side, these banks relied less on raising household deposits and more on short-term borrowing. This evidence shows that banks that relied more on borrowing operated with riskier (more exposed to withdrawal shocks) balance sheets, characterized by less liquidity and more loan exposure.

Table 8: Balance Sheet Ratios by Borrowing Status, 1922

	(1)	(2)	(3)	(4)	Difference		
	None	1911 and 1922	1911 only	1922 only	(2)–(1)	(3)–(1)	(4)–(1)
Cash to assets	4.4	2.8	2.9	2.4	-1.7*	-1.5	-2.1***
	(5.5)	(1.4)	(1.2)	(1.1)	(0.9)	(1.4)	(0.8)
Duefroms to assets	10.1	7.4	8.4	5.5	-2.7***	-1.7	-4.6***
	(5.3)	(4.4)	(4.8)	(4.3)	(1.1)	(1.5)	(1.0)
Bonds to assets	11.9	4.1	8.2	8.0	-7.8***	-3.7	-3.9
	(15.7)	(5.0)	(8.7)	(9.9)	(2.8)	(4.3)	(2.6)
Loans to assets	69.8	80.8	76.0	77.7	11.0***	6.2	8.0***
	(16.0)	(9.9)	(8.2)	(14.3)	(3.1)	(4.3)	(3.0)
Equity to liabilities	18.3	17.7	19.5	20.6	-0.6	1.2	2.3
	(6.4)	(4.9)	(7.1)	(9.8)	(1.3)	(1.9)	(1.7)
Deposits to liabilities	80.4	70.5	79.8	67.8	-9.9***	-0.6	-12.6***
	(6.6)	(9.7)	(7.3)	(16.8)	(1.8)	(2.0)	(2.6)
Duestos to liabilities	2.4	0.5	2.9	0.6	-1.9	0.5	-1.8
	(10.7)	(1.7)	(10.2)	(1.7)	(1.9)	(3.1)	(1.5)
Borrowing to liabilities	0.0	10.7	0.0	8.9	10.7***	0.0	8.9***
	(0.0)	(7.9)	(0.0)	(6.7)	(1.1)	(0.0)	(1.0)
Obs.	48	34	15	53			

As an additional test of these portfolio changes, we estimate a saturated two-period comparison across four groups of incumbent banks: *always borrowers* (those that borrowed in both 1911 and 1922), *old borrowers* (those that borrowed only in 1911), *new borrowers* (those that borrowed only in 1922), and *never borrowers* (those that did not borrow in either year). This exercise is best interpreted as heterogeneity evidence within the sample rather than as a clean causal design. Letting i denote one of the 150 banks that were present both in 1911 and 1922, and $t \in \{1911, 1922\}$, our specification is:

$$Y_{i,t} = \alpha + \eta_{1922}\mathbb{I}_{1922} + \sum_{g\in\{\text{AB,OB,NB}\}} \beta_g \mathbb{I}_{ig} + \sum_{g\in\{\text{AB,OB,NB}\}} \gamma_g \mathbb{I}_{ig} \times \mathbb{I}_{1922} + \varepsilon_{i,t}, \tag{4}$$

where $Y_{i,t}$ is a balance-sheet ratio (such as the ratio of cash to assets, or the ratio of equity to liabilities), $\mathbb{I}_{1922}$ is an indicator for the year 1922, and $\mathbb{I}_{ig}$ is an indicator that bank i belongs to borrower group $g \in \{\text{AB}, \text{OB}, \text{NB}\}$, with never borrowers as the omitted category. The error term $\varepsilon_{i,t}$ is a mean-zero and potentially heteroskedastic, and we cluster error terms at the bank level to account for serial correlation. The interaction coefficients γ_g capture the differential change between 1911 and 1922 for each borrower group relative to never borrowers. We compute them on both asset and liability sides of the balance sheet.

Table 9 presents the results for asset ratios. It shows that the creation of the Federal Reserve reduced the liquidity of the banks that borrowed: these banks lowered both cash holdings and interbank deposits. The decline in liquid assets was offset by an expansion in loans. These adjustments are most pronounced among new borrowers in 1922.

Table 9: The Effect of Borrowing on Bank Assets - 1922

	Cash to assets	Duefrom to assets	Bonds to assets	Loans to assets
Always a borrower x $\mathbb{I}_{1922}$	-2.8***	-5.6***	1.0	7.6*
	(0.5)	(1.3)	(1.8)	(2.9)
New borrower x $\mathbb{I}_{1922}$	-3.1***	-7.5***	3.5	7.0*
	(0.5)	(1.2)	(1.9)	(2.7)
Old borrower x $\mathbb{I}_{1922}$	-2.6***	-4.4**	4.2	4.3
	(0.6)	(1.6)	(2.6)	(2.8)
Observations	298	298	298	298
R2	0.095	0.271	0.080	0.056

Table 10 presents the results for liability ratios. Banks significantly changed their funding structure: they reduced deposit financing while increasing equity financing and interbank borrowing. Although our model does not explicitly analyze liability composition, these shifts have clear implications for run risk. By reducing their dependence on household deposits and increasing their reliance on short-term borrowing, banks became less exposed to withdrawals by household depositors but more exposed to runs by institutional investors: correspondent banks could curtail loans precisely when they faced liquidity shocks themselves, generating downstream contagion, a mechanism we will add in the quantitative extension of the model. Taken together, these results indicate that banks altered their funding structures, thereby altering the nature of run risk and the sources of instability in the system.

Table 10: The Effect of Borrowing on Bank Liabilities - 1922

	Equity to Liab	Deposits to Liab	Duetos to Liab	Borrowing to Liab
Always a borrower x $\mathbb{I}_{1922}$	-5.5**	-6.3*	0.8	10.9***
	(2.0)	(2.7)	(1.0)	(1.3)
New borrower x $\mathbb{I}_{1922}$	-4.9**	-5.8*	0.1	9.0***
	(1.5)	(2.3)	(0.3)	(1.0)
Old borrower x $\mathbb{I}_{1922}$	-5.0*	5.1*	2.4	0.0
	(2.2)	(2.2)	(2.6)	(0.0)
Observations	298	298	298	298
R2	0.103	0.185	-0.006	0.529

We show that these results are consistent not only when comparing 1911 with 1920 and 1921, but also when examining changes in interbank networks among nonmembers in Kansas, as presented in Appendix D.3. Unfortunately, we cannot replicate the previous analysis of changes in Kansas nonmembers' portfolios because we observe only the identity of each nonmember bank's correspondents, not the intensive margin of those relationships.

6 A Quantitative Analysis

In this section, we extend the model and conduct a disciplined quantitative exercise to evaluate the trade-off between public and private liquidity when member banks intermediate liquidity from the Fed to nonmembers. The purpose of the exercise is not to deliver a fully identified structural estimation, but rather to assess whether the mechanism developed above can generate economically meaningful magnitudes. Although this is not a full calibration, it provides us with a first tentative evaluation of the trade-off between public liquidity provision and private liquidity regulatory constraints, and the implications for output and stability.

We assume that bank x, our main object of study, retains the same structure and optimization problem as in the original setting. We now allow bank y to obtain household deposits D_y. These deposits are subject to an exogenous reserve requirement $\hat{\phi}$, and the remainder is invested in a highly illiquid project $\hat{I}_y = (1 - \hat{\phi})D_y$. Treating bank y's household deposits as exogenous allows us to maintain focus on exogenous deposit-withdrawal shocks. This extension introduces uncertainty about the amount of public liquidity available to bank x, since bank y may need to draw on some of its access to public liquidity to meet its own withdrawal shocks. Interbank deposits remain subject to reserve requirements ϕ, but in this quantitative exercise ϕ is chosen by a government planner who seeks to maximize expected output (a combination of investment levels and liquidation probabilities).

More precisely, bank y faces an early withdrawal shock from household depositors, denoted $\widehat{\zeta}_y$. We assume a binomial shock. With probability $1-\alpha_y$, withdrawals are low enough to be fully covered by the reserves imposed by the government, $\widehat{\zeta}_y < \hat{\phi} D_y$. With probability α_y, withdrawals exceed reserves and force bank y to tap public liquidity at the discount window. We assume that the required liquidity is strictly greater than reserves but still below the available public liquidity $\hat{\phi} D_y < \widehat{\zeta}_y < m$. In this sense, bank y never liquidates its own project as a response to its own withdrawals.

Formally, we define bank y's *withdrawal shock in excess of retail deposit reserves* as,

$$\zeta_y \equiv \begin{cases} \bar{\zeta}_y \equiv \widehat{\zeta}_y - \hat{\phi} D_y & \textit{with prob.} \quad \alpha_y \\ 0 & \textit{with prob.} \ 1-\alpha_y \end{cases}$$

This implies that the amount of public liquidity available to bank x after bank y uses it to satisfy its own deposit withdrawals is

$$m_x(\zeta_y) \equiv \begin{cases} m - \bar{\zeta}_y & \textit{with prob.} \quad \alpha_y \\ m & \textit{with prob.} \ 1-\alpha_y \end{cases}$$

As in the main model, bank x meets its withdrawals following a strict pecking order. It first uses its own cash reserves Φ_x. It then draws on the liquidity available from bank y, Φ_y, together with any residual public liquidity $m_x(\zeta_y)$ that remains after bank y satisfies its own withdrawals. Only once these sources are exhausted does bank x withdraw its interbank deposits L. Hence, bank x is forced to liquidate its own project if,

$$\zeta_x > \Phi_x + L + m_x(\zeta_y).$$

Liquidation Probabilities: We can now recompute survival probabilities. Now, each bank's project survival depends on the other bank's withdrawal shocks. More precisely, the bank x's unconditional survival probability of its project is

$$\Gamma = \alpha_y \, S\big(\Phi_x + L + m - \bar{\zeta}_y\big) + (1-\alpha_y)\, S(\Phi_x + L + m)\,.$$

Notice that bank y's withdrawal shock reduces the amount of public liquidity available to bank x, thereby lowering its survival probability; this is *downstream contagion.*

Conversely, bank y's project can be liquidated if bank x withdraws its interbank deposits - this is *upstream contagion.* If $\zeta_y > \Phi_y + m$, bank y liquidates for sure, but this case is ruled out by our assumption on $\widehat{\zeta}_y$. Otherwise, bank y survives if and only if bank x does not withdraw its interbank deposits. Bank x withdraws L whenever

$$\zeta_x > \Phi_x + \Phi_y + m_x(\zeta_y).$$

Thus, conditional on ζ_y, the survival probability of bank y's project is

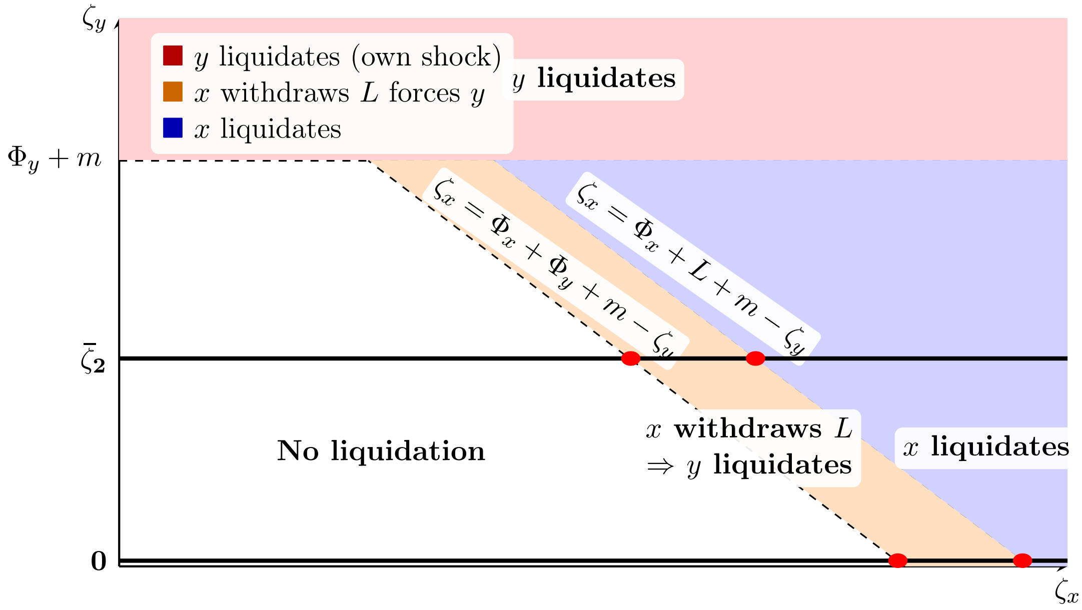
$$\Delta(\zeta_y) = \mathbf{1}\{\zeta_y \leq \Phi_y + \hat{\Phi}_y + m\}\, S(\Phi_x + \Phi_y + m_x(\zeta_y))\,.$$

The unconditional survival probability of bank y is therefore

$$\Delta = \alpha_y\, \Delta(\bar{\zeta}_y) + (1 - \alpha_y)\, \Delta(0).$$

Figure 8 extends Figure 4 (which considered only shocks to bank x) to the two-dimensional case with shocks to both bank x (horizontal axis), and bank y (vertical axis). Larger shocks to bank y require greater use of public liquidity for its own needs, reducing the amount available to bank x and increasing the probability that both projects are liquidated.

Figure 8: Regions of joint liquidity shocks (ζ_x, ζ_y).



Payoffs: As in the main setting, assuming liquidation yields recovery of principal but not returns, expected profits for bank x are

$$\Pi_x = \Gamma\, r_x I_x + \Delta\, r L,$$

while expected profits for bank y are

$$\Pi_y = X + \Delta\,(r_y I_y - \, rL).$$

where $X \equiv \hat{r}_y(1-\hat{\phi})D_y - \hat{r}D_y$ does not depend on either m or ϕ.

Planner welfare: We assume the planner chooses the amount of public liquidity, m, and the interbank reserve requirements, ϕ, to maximize welfare. Since X does not depend on these objects and bank y chooses $I_y = (1-\phi)L$, welfare is given by

$$W(m,\phi) = \Gamma(m,\phi)\, r_x I_x(m,\phi) + \Delta(m,\phi)\, r_y(1-\phi)L(m,\phi) - \frac{1}{2}\kappa m^2. \tag{5}$$

It is useful to highlight the main trade-offs introduced by m and ϕ. Public liquidity m is beneficial because it directly increases the survival probability of both projects, Γ and Δ. With more liquidity available, bank x can withstand shocks without withdrawing L or liquidating its own project. Moreover, higher public liquidity induces bank x to shift its portfolio toward productive uses and away from cash, since Φ_x weakly declines with m. However, public liquidity may be socially costly because it requires a distortionary transfer of resources from households to banks. We capture that possibility with a social cost function that is quadratic in the committed amount m, applied only in states where public liquidity is actually used (i.e., when either bank experiences a shock). In short, public liquidity has the cost of being distortionary but the benefit of being used only when needed, which means κ captures the *expected social cost of public liquidity.*

In contrast, regulation through reserve requirements ϕ is beneficial because it induces more private liquidity, reducing the need for bank x to withdraw or liquidate its own project (Γ and Δ also increase in Φ_y). Despite bank x not being subject to ϕ, the additional liquidity in the system through bank y allows bank x's portfolio to lean toward more productive uses, increasing both I_x and L. Regulation that induces private liquidity, however, is also costly, as it reduces the amount of L that bank y can invest. In a few words, private liquidity has the benefit of not being distortionary, but the cost of restricting investments even when no shock is realized afterward.

This discussion is at the heart of whether it is preferable to rely on private liquidity or to crowd it out with public liquidity at a potential welfare cost. Since both sources of liquidity prevent the liquidation of productive projects - but at different costs - the question ultimately is how high those costs are. In what follows, we take a quantitative approach to *i)* infer the public liquidity available to nonmembers from the observed changes in their portfolios and regulations between 1911 and 1922, and *ii)* infer the distortionary costs of public liquidity from assuming the Fed did not internalize that funds were being channeled through members to nonmembers. Once we have these two components, we can discuss the optimal combination of public and private liquidity for a Fed that maximizes the stability and production of both members and nonmembers (the proposed welfare above.

6.1 Calibration

Calibrating a simple model is generally challenging, and this difficulty is heightened when working with historical data, given the limited availability of detailed microdata or long time series to discipline key parameters. Instead, we construct a quantitatively disciplined exercise - rather than a full-fledged calibration - to shed light on the trade-offs that determine the optimal combination of public liquidity provision and private liquidity regulation.

Parameters that we take from external sources are reported in Table 11. Parameters that are unique to the setting, such as the structure of withdrawal shocks, the relative benefit of cash and interbank deposits, the volume of public liquidity nonmembers expected to be available to borrow from members, and the probability that members suffer withdrawal shocks, are calibrated in three consecutive steps:

Table 11: Calibration: External Parameters

Parameter	Value	Source
D	1	normalization
α_x	1	normalization
r	0.02	Cox (1966)
r_x and r_y	0.06	Cox (1966)
n	1/3	FRB (1932)
$\bar{\zeta}_y$	0.03	robustness

1. **Matching nonmembers' portfolios in 1911:** We start by noting that bank x's portfolio is an endogenous choice based on expected withdrawal shocks and available public and private liquidity in the system. To match the measured portfolio of nonmember banks in 1911, we impose $m = 0$ and $\phi = 0.25$, corresponding to the level of public liquidity and reserve requirements in 1911 before the creation of Fed. In 1911, nonmember banks held 6.7% of cash and 18.3% of interbank deposits as a fraction of total deposits (4.7% and 12.7% out of 69.4% in Table 2).

Given m and ϕ, the endogenous portfolio choice helps us discipline the effective withdrawal risk faced by nonmembers. For tractability in this quantitative exercise, we set $\alpha_x = 1$ and let the shape of effective shocks be governed by a truncated Gamma distribution with parameters θ/k, as in the example supporting our pecking-order characterization in Corollary 1.[24] Since we have two moments to match - and shocks tend to reduce both cash and deposits - we introduce a relative benefit of cash in meeting withdrawals relative to interbank deposits, particularly in this historical setting. We denote this relative difference by λ. Fixing $k = 1$, we obtain $\theta = 0.086$ and $\lambda = 0.812$.

2. **Matching nonmembers' portfolios in 1922:** Once we have recovered the structure of shocks, and assuming it was not affected by the Fed's creation, we ask what amount of public liquidity would justify the portfolio observed for bank x in 1922, given that the Fed effectively reduced reserve requirements to 13%. Accordingly, we match the measured 1922 portfolio, composed of 4.5% of cash and 12.5% of interbank deposits as a fraction of total deposits (3.3% and 8.9% out of 70.9% in Table 2).

Given the structure of shocks and the updated ϕ, changes in nonmember banks' portfolios are informative about the public liquidity they expected to obtain. In the model, the amount of public liquidity depends on the probability that members experience a shock, α_y, and the size of that shock, $\bar{\zeta}_y$. We assume that the average shock, when it occurs, is covered by private liquidity, so $\bar{\zeta}_y < \phi_{1911} L_{1911} = 0.046$. For this benchmark calibration, we set $\bar{\zeta}_y = 0.03$ and provide robustness later. Given these choices, we obtain $m = 0.049$ and $\alpha_y = 0.984$. That is, the data require sufficient public liquidity to justify the large decline in nonmembers' cash and deposits, despite the reduction in members' required private liquidity holdings.

3. **Matching public liquidity passthrough** Once we have determined the extent of nonmembers' expected public liquidity to justify their portfolio changes, and based on the average pass-through of 20% documented in Section 4, we infer the distortionary cost of public liquidity κ. To do this, we need to take a stand on how the Fed understood such pass-through. We assume the Fed believed that no public liquidity flowing to members was used to lend to nonmembers. Since we calibrated m as the public liquidity nonmembers expected to receive - and that constituted on average 20% of the total public liquidity provided by the Fed - the implied total amount of public liquidity is $\widehat{m} = 5(a_y m + (1 - a_y)(m - \bar{\zeta}_y)) = 5m - 5(1 - a_y)\bar{\zeta}_y = 0.241$. The Fed would have chosen this amount of public liquidity such that the marginal expected benefit equaled its marginal social cost, $r_y I_y = \kappa \widehat{m}$, or $\kappa = \frac{r_y I_y}{\widehat{m}}$.

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[24] The parameter α_x was useful in the theoretical section to illustrate qualitatively the reaction of portfolios to expected shocks, just moving one parameter. In the quantitative analysis, this is irrelevant, and it is more important to capture the expected shock.

This computation yields $\kappa = 0.031$. Note that κ includes the probability that $\widehat{m}$ is actually used; it should therefore be interpreted as the *expected social cost of public liquidity.*

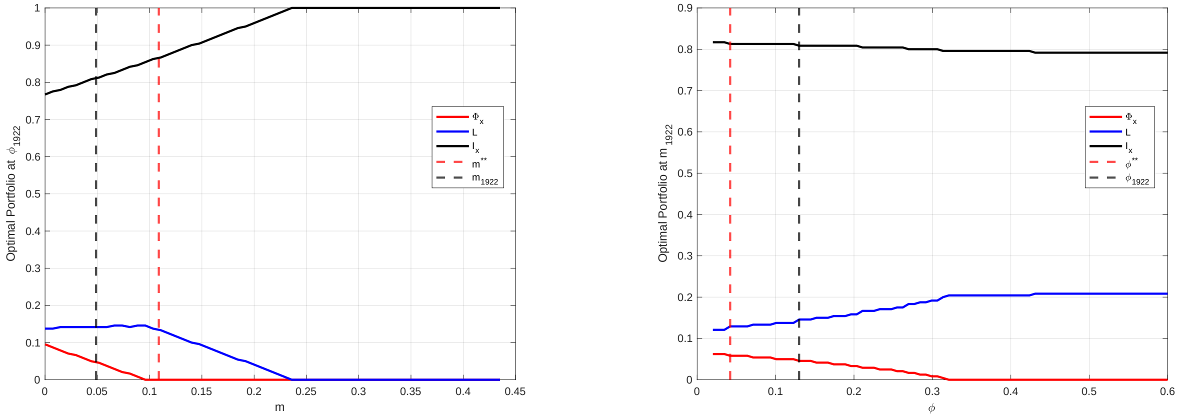
Table 12 summarizes these five internally calibrated parameters and the corresponding moments. Appendix E provides additional details on the calibration strategy.

Table 12: Calibration: Internal Parameters and Targets

Internal Parameters		Targets		
Parameter	Value	Moment	Target	Model
Gamma shocks $\frac{\theta}{k}$	0.086	1911 - Cash/D	6.7%	6.6%
Discount liqu. λ	0.812	1911 - L/D	18.3%	17.5%
m in 1922	0.049	1922 - Cash/D	4.5%	4.6%
α_y	0.984	1922 - L/D	12.5%	14.1%
κ	0.031	$\frac{r_y I_y}{\hat{m}}$ in equilibrium		

The two panels in Figure 9 show how bank x's optimal portfolio responds to the two policy instruments, m and ϕ, evaluated at their estimated 1922 levels ($m = 0.049$ and $\phi = 0.13$). The figure shows that both instruments reduce cash holdings. Their effects on I_x (and, by extension, on L) differ, however. More public liquidity induces nonmembers to invest more in their own projects and less in interbank deposits. In contrast, higher reserve requirements have the opposite effect. The reason is that interbank deposits look more like cash (as a larger fraction is held as cash by members) but offer higher returns, making them relatively more attractive when ϕ rises.

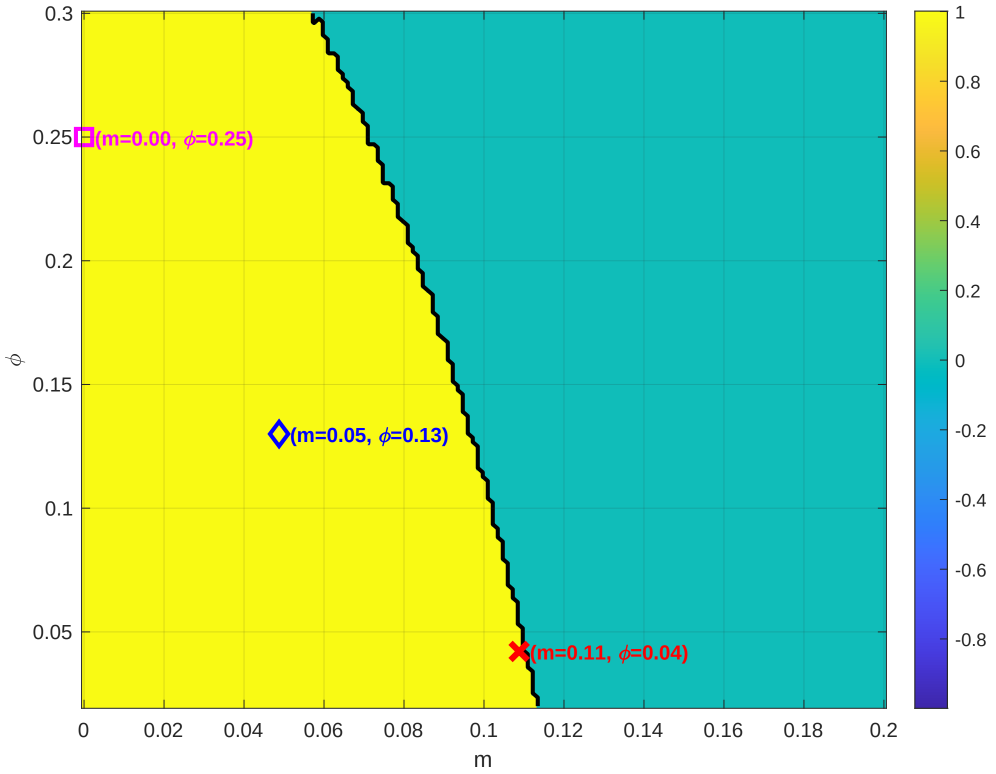
Figure 9: Optimal Portfolio of Nonmembers



Optimal provision of public liquidity and regulation of private liquidity Finally, we can put our calibration to work. Using the backed-out value of κ, we compute full welfare (5) under the assumption that the Fed internalizes that members lend to nonmembers, thereby preventing liquidations not only from member shocks but also from nonmember shocks that could otherwise trigger interbank withdrawals. Internalizing upstream contagion implies the Fed would further reduce reserve requirements and provide even more public liquidity, shifting the balance away from private liquidity. The optimal policy combination is $m^* = 0.109$ and $\phi^* = 0.042$. In relative terms, this implies roughly doubling the provision of public liquidity (from 0.049 to 0.109) and reducing reserve requirements by almost 9 percentage points (from 13% to 4 %). The implication for portfolios is illustrated in Figure 9.

Figure 10 illustrates the combination of the two regulatory tools. The yellow region represents policy pairs that lead bank x to hold positive cash, while the blue region represents combinations that induce bank x to hold no cash. In this figure, we highlight the policy combinations before the Fed (calibrated to nonmembers in 1911) and after the Fed (calibrated to nonmembers in 1922), along with our estimate of the optimal policy prescription.

Figure 10: Calibration Scenarios



Our calibration is consistent with a relatively low social cost of public liquidity if the Fed only considered members' operations, oblivious to interbank networks. Under that view, expanding public liquidity so that nonmember banks also benefit would be justified even without changing reserve requirements. More public liquidity induces nonmembers to hold almost no cash, to reduce their interbank deposits (by 6%), and to increase their own investments (by 7%). Lower reserve requirements further allow members to invest more despite the decline in interbank deposits (a net increase of about 4%). Together, these changes generate a substantial rise in investment with no increase in the probability of liquidation for either bank - an expansion in investment without an accompanying rise in financial fragility.

This result is, of course, quantitative, not qualitative. The prescription of reducing reserve requirements while increasing public liquidity would revert under different - and somewhat implausible - external parameters. For instance, if the return on members' investment projects were very high ($r_y > 0.2$), the implied cost of public liquidity would be higher, making it optimal for the Fed to raise reserve requirements even as it expanded public liquidity. Likewise, higher reserve requirements would be justified if the return on nonmembers' investment projects were lower ($r_x < 0.03$) or there were fewer nonmembers ($n < 1/8$), since in those cases the implicit insurance value of public liquidity for shadow banks would be smaller.

These results are informative about the conditions under which it is optimal to tighten regulations when providing more public support. This is the case when the shadow banking system is small or weakly connected to members. But when shadow banks are prevalent and highly interconnected in ways that can transmit shocks upstream to members, the Fed may prefer to prevent interbank withdrawals by providing more public support to nonmembers. Because shadow banks would respond by depositing less with members, the Fed would want to offset this disintermediation by lowering reserve requirements that otherwise constrain members' ability to invest in productive opportunities.

Alternative Regulations: Other policies may affect the balance between public and private liquidity available to nonmembers. One is restricting the pass-through of public liquidity to nonmembers - for instance, by tightening the conditions under which member banks lend. This would be optimal only if the social cost of public liquidity were sufficiently high, in which case the Fed would prefer to rely more on private liquidity, and restricting indirect access for nonmembers would force them to hold more cash.

7 Conclusion

Academics and policymakers have long debated how public liquidity reshapes interbank markets. We study this question using new historical evidence on Virginia state banks before and after the creation of the Federal Reserve System. Our data separately identify the interbank deposit and borrowing networks of nonmember banks. We document that, after the Fed, nonmembers held less cash and fewer interbank deposits, relied more on short-term borrowing from member correspondents, and shifted both networks toward more local counterparties.

These patterns sharpen the distinction between vulnerability and fragility. Nonmembers became more vulnerable, as they held less private liquidity and relied more on external funds to absorb withdrawals. But the effect on fragility depends on how much public liquidity they reach through their member correspondents. The 1920–21 evidence suggests that this indirect access was economically meaningful: member banks passed through a sizeable fraction of discount-window borrowing to nonmembers, especially at the peak of the recession.

Our model rationalizes these joint changes in portfolios and network through a simple mechanism: once public liquidity becomes available through member correspondents, the value of precautionary liquidity and of interregional private liquidity insurance declines. Banks, therefore, reduce private liquidity buffers, rely more on borrowing upon facing withdrawal shocks, and reorient their correspondent relationships. We use this framework in a disciplined quantitative exercise to study the trade-off between public liquidity provision and reserve requirements that regulate private liquidity holdings.

Our findings provide a conjectural interpretation of larger system-wide crises. In our setting, indirect access to public liquidity can make the system more resilient to idiosyncratic or regional shocks while at the same time leaving banks with thinner private liquidity buffers. This mechanism may help explain why the system performed relatively well in the 1920–21 recession, when liquidity support flowed from member correspondents to distressed nonmembers, yet could become much more fragile when distress originated higher in the hierarchy, as in the early 1930s. Exploring that connection directly would require extending the evidence beyond Virginia and into the Depression years, which we leave for future work.

The same logic may also apply to modern shadow banking. Institutions outside the formal safety net may still obtain effective access to public liquidity through their links with regulated intermediaries. When that possibility is anticipated, they may choose to hold less private liquidity and rely more heavily on contingent support. This can improve resilience in ordinary disturbances but create tail events and a heightened fragility during severe aggregate stress. We have also shown that regulations should be tightened when providing more public support, only when shadow banking is relatively small, unconnected, and/or without access to projects with very high returns. If these conditions do not hold in modern times, tightening regulations while providing public liquidity may backfire, as shadow banks would crowd out traditional banks and use them only as a conduit to the public liquidity. We also view applying these insights and methodologies as a promising direction for future research focused on the fragility generated by modern shadow banking operations.

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A Proofs of Propositions and Lemmas

Proof of Lemma 1

Proof. Fix (I_x, L, Φ_x) chosen by bank x. Bank y chooses $I_y \in [0, (1-\phi)L]$, equivalently $\Phi_y = L - I_y \in [\phi L, L]$, to maximize

$$\Pi_y = \Delta(I_x, L, \Phi_x, \Phi_y)\bigl(I_y r_y - Lr\bigr).$$

The feasible set is compact and Π_y is continuous, so an optimum exists. Using $\Phi_y = L - I_y$ and $d\Phi_y/dI_y = -1$,

$$\frac{d\Pi_y}{dI_y} = r_y\Delta - (I_y r_y - Lr)\,\partial_{\Phi_y}\Delta.$$

By assumption, this derivative is strictly positive for every feasible I_y:

$$r_y\Delta > (I_y r_y - Lr)\,\partial_{\Phi_y}\Delta \quad \text{for all } I_y \in [0, (1-\phi)L].$$

Hence Π_y is strictly increasing in I_y, so the unique maximizer is the upper bound $I_y^* = (1-\phi)L$. Translating back to reserves:

$$\Phi_y^* = L - I_y^* = L - (1-\phi)L = \phi L.$$

□

Proof of Proposition 1

Proof. Work in the baseline $(m = 0)$. By Lemma 1, bank y sets $\Phi_y = \phi L$ on path. Bank x solves

$$\max_{I_x, L, \Phi_x} \ \Pi_x = \Gamma I_x r_x + \Delta L r$$

subject to

$$\mathcal{X} := \{(I_x, L, \Phi_x) : I_x, L, \Phi_x \geq 0,\ I_x + L + \Phi_x \leq D\}.$$

With $\Phi_y = \phi L$,

$$\Gamma = (1-\alpha_x) + \alpha_x S(\Phi_x + L),$$

$$\Delta = (1-\alpha_x) + \alpha_x[S(\Phi_x + \phi L) + S(\Phi_x + \phi L + I_x) - S(\Phi_x + L)]\,.$$

By compactness of $\mathcal{X}$ and strict concavity of Π_x, there is a unique optimizer

$$(I_x^*(\alpha), L^*(\alpha), \Phi_x^*(\alpha)).$$

Step 1: explicit directional margins. The required partial derivatives are

$$\partial_{I_x}\Pi_x = r_x\Gamma + \alpha_x r L\, s(\Phi_x + \phi L + I_x),$$

$$\begin{aligned}\partial_L\Pi_x &= \alpha_x r_x I_x s(\Phi_x + L) + r\Delta \\ &\quad + \alpha_x r L[\phi s(\Phi_x + \phi L) + \phi s(\Phi_x + \phi L + I_x) - s(\Phi_x + L)]\,,\end{aligned}$$

$$\partial_{\Phi_x}\Pi_x = \alpha_x r_x I_x s(\Phi_x + L) + \alpha_x r L[s(\Phi_x + \phi L) + s(\Phi_x + \phi L + I_x) - s(\Phi_x + L)]\,.$$

At $L = 0$, along direction $(-1, +1, 0)$,

$$\begin{aligned}\mathcal{M}_L(\alpha_x) &= \big(-\partial_{I_x}\Pi_x + \partial_L\Pi_x\big)\Big|_{(I_x^0, 0, \Phi_x^0)} \\ &= r - r_x\big[(1-\alpha_x) + \alpha_x S(\Phi_x^0)\big] + \alpha_x r_x I_x^0 s(\Phi_x^0).\end{aligned}$$

At $\Phi_x = 0$, along direction $(-1, 0, +1)$,

$$\begin{aligned}\mathcal{M}_\Phi(\alpha_x) &= \big(-\partial_{I_x}\Pi_x + \partial_{\Phi_x}\Pi_x\big)\Big|_{(I_x^L, L_x^L, 0)} \\ &= r_x\big[\alpha_x I_x^L s(L_x^L) - (1-\alpha_x) - \alpha_x S(L_x^L)\big] + \alpha_x r L_x^L\big[s(\phi L_x^L) - s(L_x^L)\big]\,.\end{aligned}$$

Step 2: cutoff for deposit entry. By assumption (ii), $\mathcal{M}_L$ is continuous and single crossing, so there exists unique α_L with $\mathcal{M}_L(\alpha_L) = 0$. Since the problem is strictly concave, KKT conditions are sufficient:

$$\alpha_x < \alpha_L \Rightarrow L^*(\alpha_x) = 0, \qquad \alpha_x > \alpha_L \Rightarrow L^*(\alpha_x) > 0.$$

Step 3: cutoff for cash entry given active deposits. By assumption (iii), $\mathcal{M}_\Phi$ is continuous and single crossing, with unique root $\alpha_\Phi > \alpha_L$. Therefore

$$\alpha_L < \alpha_x < \alpha_\Phi \Rightarrow \Phi_x^*(\alpha_x) = 0, \qquad \alpha_x > \alpha_\Phi \Rightarrow \Phi_x^*(\alpha_x) > 0.$$

Step 4: regime characterization. If $\alpha_x < \alpha_L$, both liquidity margins are inactive. With positive returns and linear constraints, the full budget is allocated to own investment:

$$(I_x, L, \Phi_x) = (D, 0, 0).$$

Combining with Steps 2–3 yields

$$\alpha_x < \alpha_L : \ (I_x, L, \Phi_x) = (D, 0, 0), \quad \alpha_L < \alpha_x < \alpha_\Phi : \ L > 0, \ \Phi_x = 0, \quad \alpha_x > \alpha_\Phi : \ L > 0, \ \Phi_x > 0.$$

□

Proof of Proposition 2

Proof. Fix $m \in [0, D]$ and define shifted primitives

$$S_m(z) := S(z + m), \qquad s_m(z) := s(z + m).$$

With public liquidity, every continuation argument in Γ, Δ is shifted by m, so the objective has exactly the same structure as in Proposition 1, replacing (S, s) by (S_m, s_m). Thus, for constrained optimizers $(I^0_{x,m}, \Phi^0_{x,m})$ and $(I^L_{x,m}, L^L_{x,m})$,

$$\mathcal{M}^m_L(\alpha_x) = r - r_x\big[(1 - \alpha_x) + \alpha_x S_m(\Phi^0_{x,m})\big] + \alpha_x r_x I^0_{x,m} s_m(\Phi^0_{x,m}),$$

$$\mathcal{M}^m_\Phi(\alpha_x) = r_x\big[\alpha_x I^L_{x,m} s_m(L^L_{x,m}) - (1 - \alpha_x) - \alpha_x S_m(L^L_{x,m})\big] + \alpha_x r L^L_{x,m}\big[s_m(\phi L^L_{x,m}) - s_m(L^L_{x,m})\big].$$

By the proposition assumptions, strict concavity and single crossing hold for these shifted margins. Applying the same KKT argument as in Proposition 1 yields cutoffs $\alpha_L(m)$ and $\alpha_\Phi(m)$ with

$$0 < \alpha_L(m) < \alpha_\Phi(m) < 1$$

and regimes

$$\alpha_x < \alpha_L(m) \Rightarrow (I_x, L, \Phi_x) = (D, 0, 0),$$

$$\alpha_L(m) < \alpha_x < \alpha_\Phi(m) \Rightarrow L > 0, \ \Phi_x = 0,$$

$$\alpha_x > \alpha_\Phi(m) \Rightarrow L > 0, \ \Phi_x > 0.$$

□

Proof of Corollary 1

Proof. Along $\Phi_x = 0$ and $I_x = D - L$,

$$\mathcal{M}_\Phi(\alpha_x; L) = r_x[\alpha_x(D-L)s(L) - (1-\alpha_x) - \alpha_x S(L)] + \alpha_x r L[s(\phi L) - s(L)]\,.$$

Differentiating with respect to L:

$$\partial_L \mathcal{M}_\Phi(\alpha_x; L) = \alpha_x\, \Xi(L),$$

$$\Xi(L) = r_x[(D-L)s'(L) - 2s(L)] + r\big[s(\phi L) - s(L) + L\big(\phi s'(\phi L) - s'(L)\big)\big]\,.$$

Hence $\Xi(L) < 0$ for all $L \in (0, D)$ implies strict strong substitutability: larger deposits lower the net marginal value of cash.

At $L = 0$,

$$\mathcal{M}_L(\alpha_x) = \mathcal{M}_\Phi(\alpha_x; 0) + r,$$

so deposits weakly enter before cash. With strict interior endpoint signs, the order is strict:

$$0 < \alpha_L < \alpha_\Phi < 1.$$

For truncated Gamma shocks,

$$s_{k,\theta}(z) = \frac{z^{k-1}e^{-z/\theta}}{\theta^k \Gamma(k)\, F_\Gamma(D; k, \theta)}, \qquad s'_{k,\theta}(z) = s_{k,\theta}(z)\left(\frac{k-1}{z} - \frac{1}{\theta}\right).$$

Substituting these into Ξ gives $\Xi_{k,\theta}(L)$ in Corollary 1. Therefore the primitive condition on (k, θ) is

$$\Xi_{k,\theta}(L) < 0 \quad \forall L \in (0, D).$$

In particular, $0 < k \leq 1$ and any θ such that the inequality holds globally imply strong substitutability and the pecking order. $\square$

Proof of Proposition 3

Proof. Under Assumption 1, each core bank x_i has effective liquidity

$$\widetilde{m}_i = m + \phi L_j, \qquad j \neq i,$$

that is, direct public liquidity plus coinsurance capacity from the paired core bank. Holding primitives fixed, each periphery bank's portfolio problem is the same as in the two-bank model, with continuation terms evaluated at $\widetilde{m}_i$.

Let $L_i^*(\widetilde{m}_i)$ denote the optimal deposit from a periphery bank into core bank i. By the pecking-order result (Proposition 2 and its m-generalization in the proof), higher effective liquidity weakly reduces the marginal value of private deposit insurance. Hence $L_i^*(\cdot)$ is weakly decreasing in $\widetilde{m}_i$.

Without coinsurance, effective liquidity is m. With coinsurance, it is $m+\phi L_j \geq m$. Therefore

$$L_i^*(m+\phi L_j) \leq L_i^*(m).$$

So equilibrium periphery deposits into the core are weakly lower under coinsurance than in the benchmark without coinsurance, holding m fixed. This proves the proposition. $\square$

Proof of Proposition 4

Proof. Let net values of choosing a core or local correspondent be

$$V_C(m) - \kappa_C, \qquad V_R(m) - \kappa_R,$$

with $\kappa_C > \kappa_R$ the higher maintenance cost of core links. Define the incremental gross benefit of core over local:

$$\Delta(m) := V_C(m) - V_R(m),$$

and the net advantage:

$$H(m) := \Delta(m) - (\kappa_C - \kappa_R).$$

By assumption and the pecking-order substitution logic, public liquidity reduces the insurance value of extra diversification, so $\Delta(m)$ is continuous and decreasing, hence $H(m)$ is continuous and decreasing.

Banks choose core iff $H(m) \geq 0$. Consider three cases:

1. If $H(m) \geq 0$ for all m in the admissible set, core is always chosen.
2. If $H(m) \leq 0$ for all m, local is always chosen.
3. Otherwise, by continuity and monotonicity there exists a unique cutoff m_c such that $H(m_c) = 0$.

In the interior-cutoff case,

$$m < m_c \Rightarrow H(m) > 0 \Rightarrow \text{core links},$$

$$m > m_c \Rightarrow H(m) < 0 \Rightarrow \text{local links}.$$

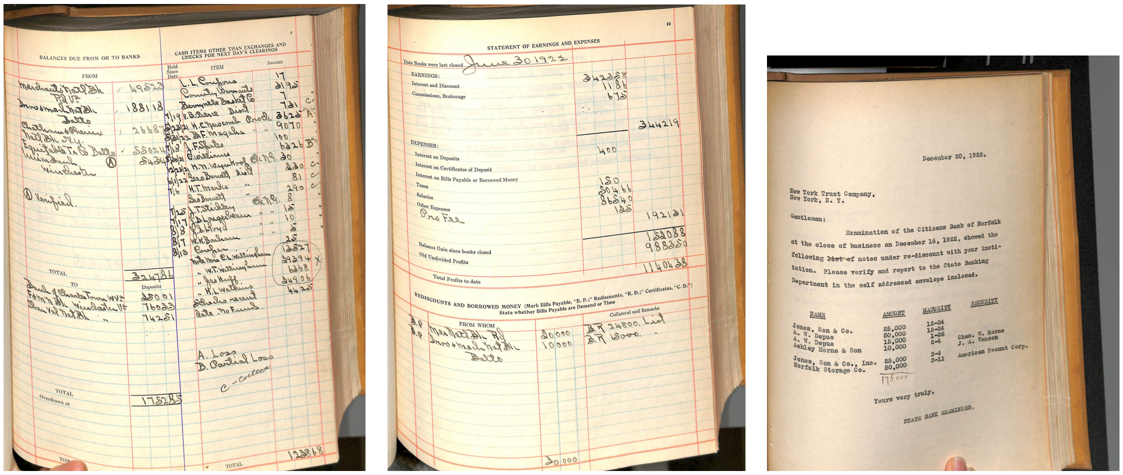
Therefore equilibrium network geography shifts from core concentration toward local concentration as public liquidity increases. ☐

B Details of the Novel Data on Virginia Banks

B.1 Virginia State Bank Examination Reports

In Figure B1 we present images of representative pages in the state bank examination reports used for this study. The reports provide information on three types of interbank relationships: on the asset side of the balance sheet, the amounts due from other banks by each debtor banks; on the liability side of the balance sheet, the amounts due to other banks by each creditor banks; and the amounts of borrowed money and the provider of these short-term loans. In some cases, the reports provide information on collateral pledged to secure short-term funds.

Figure B1: Virginia State Bank Examination Reports



Interbank Deposits

Short-term Borrowing

Collateral for Borrowing

December 20, 1922.

New York Trust Company,
New York, N. Y.

Gentlemen:

Examination of the Citizens Bank of Norfolk at the close of business on December 16, 1922, showed the following ~~list of~~ notes under re-discount with your institution. Please verify and report to the State Banking Department in the self addressed envelope inclosed.

NAME	AMOUNT	MATURITY	SECURITY
Jones, Son & Co.	25,000	12-24	
A. W. Depue	50,000	12-24	
A. W. Depue	15,000	1-28	Chas. W. Horne
Ashley Horne & Son	10,000	2-4	J. A. Venson
Jones, Son & Co., Inc.	25,000	3-4	American Peanut Corp.
Norfolk Storage Co.	50,000	3-11	
	175,000		

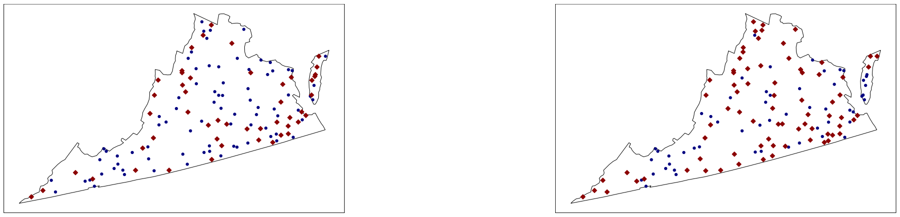
Yours very truly,

STATE BANK EXAMINERS.

Figure B2: Respondent and Correspondent Banks, 1911 and 1922

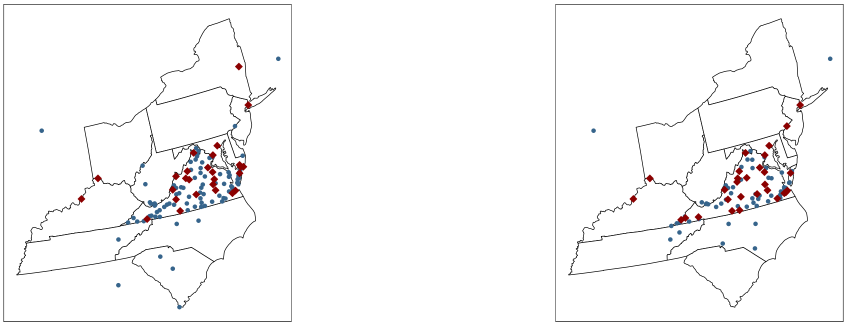
Panel A : Respondent banks

1911 1922



Panel B : Correspondent banks

1911 1922

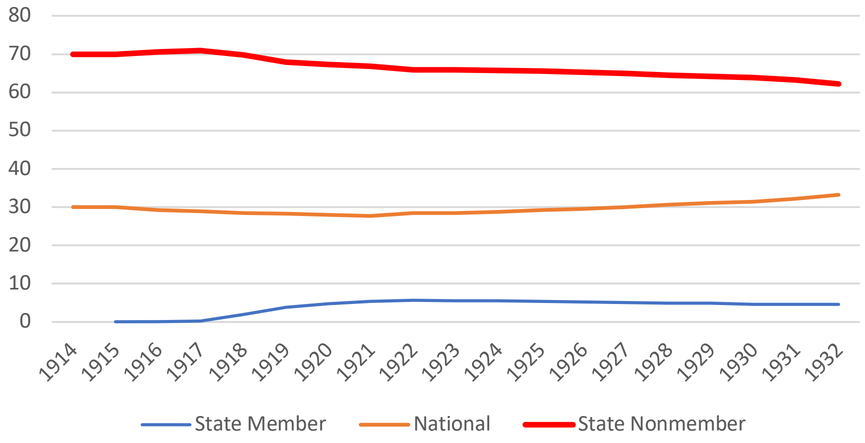


Notes: Figure B2 maps all respondent banks (Virginia state banks) and correspondent banks for the years 1911 and 1922. The respondent (corresponding) banks that *only* placed (received) deposits are in blue, while banks that *both* placed (received) deposits and borrowed (lent) short-term funds are in red.
Source: *Virginia State Bank Examination Reports*.

B.2 Importance of Nonmember Banks

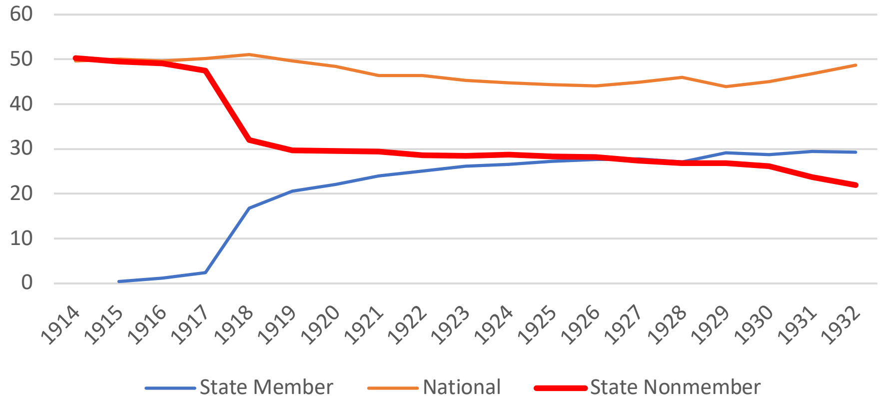
Nonmember banks were important for the banking system. We rely on a special report that the Federal Reserve System published in 1932 to examine the dual banking system and provide the number of national, state member, and state nonmember banks and the share of loans held by each of them. Figure B3 shows the proportion of nonmember banks in total commercial banks in Virginia from 1914 to 1929. Only 5% of state banks that could opt for membership had become members by 1929. Figure B4 shows the share of loans and investments held by state nonmember banks. When the Fed was created, state banks accounted for about 50 percent of all loans and investments by all banks in Virginia. After the 13 state banks that chose to join became members (and are *not* part of our analysis), this share declined to about 30 percent, with those member state banks accounting for much of the remaining activity.The state banks that remained outside the Federal Reserve System still represented a sizeable fraction of lending in Virginia.

Figure B3: Share of Member and Nonmember Banks in Virginia



Nonmember banks were also important for member banks. While our dataset documents the connections of nonmembers - and thus the importance of members for nonmembers - we lack comprehensive information on how important nonmembers were for members' portfolios. The interbank connections that allow us to examine members' portfolios come primarily from the distinction between state and national banks. All national banks became Fed members, while some state banks did as well, and their relationships changed markedly after joining. With this caveat in mind, Table B1 reports the interbank deposits held by member banks and due to state banks (both state members and state nonmembers after the Fed). Before the Fed, state banks accounted for roughly 50% of all national banks' interbank deposits. This share rose to an average of 65% after the Fed's creation, even as member banks reduced

Figure B4: Share of Loans Made by Member and Nonmember Banks in Virginia



their own interbank deposits, largely because those deposits no longer counted toward reserve requirements. The detailed figures appear in the table.

Table B1: Vault Cash and Interbank Deposits by Year

Year	Vault Cash	Due to Interbank Deposits		State/ National
		Due to National	Due to State	
1910	4,084,520	4,606,024	4,425,721	0.49
1911	4,373,637	5,008,245	4,816,368	0.49
1912	4,504,696	5,291,524	4,976,492	0.48
1913	4,444,456	5,142,865	4,961,676	0.49
1914	4,724,865	4,893,324	5,079,310	0.51
1917	2,090,153	3,281,627	5,040,956	0.61
1918	2,373,512	6,257,329	9,705,531	0.61
1919	2,447,386	6,373,342	10,200,000	0.62
1920	2,435,024	5,534,486	9,280,692	0.63
1921	1,683,583	3,364,017	6,273,689	0.65
1922	1,536,977	4,179,285	7,105,189	0.63
1923	1,251,251	3,087,419	5,502,049	0.64
1924	1,298,316	3,732,491	6,427,914	0.63
1925	1,309,446	3,506,417	6,262,474	0.64
1926	961,659	2,414,880	4,762,613	0.66
1927	1,304,642	3,249,869	6,630,308	0.67
1928	1,269,489	1,504,269	3,264,842	0.68

All in all, this evidence from member banks shows that nonmember banks were not only sizeable and relevant in the broader banking system, but were also heavily interconnected with member banks, both through interbank deposits and short-term borrowing.

To compare nonmembers with members, Table B2 reports the balance-sheet information of national, state member, and state nonmember banks in Virginia. There were more state banks than national banks; they were smaller in size but still represented 27% of all loans in Virginia, held less cash and interbank deposits (about 21% of the system), and borrowed slightly less (about 23% of the system). We take this as evidence that nonmembers were numerous, smaller, but still overall sizeable within the Virginia banking system.

Table B2: Portfolios of National, State Member, and State Nonmember Banks (1922)

	Total (Thousand USD)	Percentage against Total Resources		
	All	National	State Member	State Nonmember
Loans and Securities	659,936	64	8	27
Real Estate, Furniture and Fixtures	27,202	57	8	35
Cash and Interbank Deposits	110,785	70	9	21
Other	12,628	56	23	21
	810,551	65	9	27
Capital	79,140	53	9	39
Surplus and Undivided Profits	69,987	63	10	27
Deposits	585,557	65	8	27
Borrowed Money	38,813	68	10	23
Other	37,086	84	10	6
	810,582	65	9	27
Number of Richmond Banks	22	6	4	12
Number of Country Banks	477	172	9	296

Table B3 shows the percentage of each asset and liability class relative to total assets and liabilities for each bank membership category. On the asset side, state nonmember banks held more investments and fewer liquid assets than national and state member banks. On the liability side, nonmember banks held more capital than national and state member banks. Although all three types of banks held similar shares of borrowed money, the source of these funds differed: nonmember banks obtained funds from other banks, whereas national and state member banks borrowed from the Federal Reserve.

Table B3: Balance Sheet Ratios as Fraction of Portfolios (1922)

	National	State Member	State Nonmember
Against Total Assets			
Loans and Securities	81	79	83
Real Estate, Furniture and Fixtures	3	3	4
Cash and Interbank Deposits	15	15	11
Other	1	4	1
Against Total Liabilities			
Capital	7	9	13
Surplus and Undivided Profits	8	10	9
Deposits	72	70	73
Borrowed Money	5	5	4
Other	7	6	1

B.3 Additional Analysis of Changes in Network Structures

Table B4: Distribution of Interbank Deposits, Incumbents vs. New Entrants, 1922

	Extensive Margin (Links)			Intensive Margin (Amount)		
	Existing Bank	New Bank	Difference	Existing Bank	New Bank	Difference
New York City	17.4	8.59	8.82***	9.57	4.62	4.95***
	(17.0)	(15.2)	1.81	(15.0)	(12.5)	1.55
Chicago	0.0351	0	0.0351	0.0108	0	0.0108
	(0.430)	(0)	0.0333	(0.132)	(0)	0.0103
Baltimore	9.85	4.37	5.48***	9.66	4.64	5.02**
	(19.6)	(12.7)	1.84	(21.9)	(17.3)	2.21
Washington, DC	1.32	2.16	-0.845	0.581	2.47	-1.89
	(6.03)	(12.3)	1.11	(4.65)	(14.1)	1.21
Richmond	23.2	21.3	1.91	32.3	22.9	9.46**
	(24.0)	(30.8)	3.13	(34.0)	(34.9)	3.88
Reserve Cities in Other States	2.89	4.02	-1.14	3.68	4.34	-0.656
	(10.6)	(15.9)	1.53	(14.9)	(18.3)	1.89
Country Banks in VA	42.9	56.4	-13.5***	42.6	58.6	-16.0***
	(30.5)	(36.8)	3.83	(37.6)	(42.1)	4.51
Country Banks in Other States	2.41	3.14	-0.725	0.813	2.57	-1.76*
	(7.58)	(12.3)	1.16	(4.47)	(12.2)	1.06
Obs.	150	166		150	166	

Source: Virginia State Bank Examination Reports.

Table B5: Distribution of Interbank Borrowing, Incumbents vs. New Entrants, 1922

	Extensive Margin (Links)			Intensive Margin (Amount)		
	Existing Bank	New Bank	Difference	Existing Bank	New Bank	Difference
New York City	13.3	4.10	9.23***	13.2	4.16	9.01**
	(27.3)	(14.5)	3.43	(27.9)	(15.1)	3.49
Baltimore	8.66	5.31	3.35	8.45	5.07	3.37
	(25.3)	(20.7)	3.60	(25.5)	(20.4)	3.59
Washington, DC	1.15	1.25	-0.101	1.15	1.23	-0.0851
	(10.7)	(11.2)	1.70	(10.7)	(11.1)	1.68
Richmond	28.1	12.5	15.6***	29.2	13.2	15.9***
	(39.0)	(28.7)	5.34	(40.1)	(30.1)	5.50
Reserve Cities in Other States	2.39	6.40	-4.00	2.98	6.27	-3.29
	(12.6)	(21.7)	2.72	(14.7)	(22.1)	2.88
Country Banks in VA	35.7	57.8	-22.2***	35.6	57.6	-22.0***
	(40.6)	(44.5)	6.58	(41.9)	(45.2)	6.72
Country Banks in Other States	10.7	12.6	-1.91	9.53	11.2	-1.65
	(23.5)	(27.9)	3.98	(23.9)	(27.1)	3.94
Obs.	87	80		87	81	

Source: Virginia State Bank Examination Reports.

C Robustness Using Other Years and Places

C.1 Comparing 1911 to 1920

Table C6: Balance-Sheet Ratios, Virginia State Banks, 1911 and 1920

	All Banks			Both in 1911 and 1920		
	1911	1920	Difference	1911	1920	Difference
Cash to assets	4.8	3.1	-1.6***	4.7	3.1	-1.6***
	(2.9)	(1.8)	(0.2)	(2.8)	(1.7)	(0.3)
Due-froms to assets	12.7	9.2	-3.5***	12.8	8.9	-3.9***
	(7.5)	(6.9)	(0.6)	(7.5)	(6.8)	(0.8)
Bonds to assets	3.6	10.2	6.6***	3.6	11.5	7.9***
	(7.3)	(10.4)	(0.8)	(7.3)	(9.6)	(0.9)
Loans to assets	72.3	73.3	1.0	72.4	72.8	0.5
	(13.3)	(13.6)	(1.2)	(13.7)	(12.3)	(1.4)
Equity to liabilities	25.1	16.7	-8.4***	24.5	15.5	-9.0***
	(9.2)	(8.6)	(0.8)	(8.9)	(6.8)	(0.9)
Deposits to liabilities	69.5	73.5	4.0***	70.4	75.1	4.6***
	(13.2)	(15.5)	(1.3)	(12.7)	(14.0)	(1.5)
Dueto to liabilities	1.5	0.9	-0.6	1.7	1.0	-0.7
	(7.0)	(2.9)	(0.5)	(7.7)	(3.3)	(0.6)
Borrowing to liabilities	3.5	7.0	3.5***	3.1	6.7	3.6***
	(6.0)	(9.0)	(0.7)	(5.4)	(8.0)	(0.7)
Obs.	206	291		170	169	

Table C7: Exposures to the Largest Depository Correspondent

	Existing - Across Years			Across Banks		
	1911	1920	Difference	Existing	New	Difference
Due from to total due froms	65.7	61.1	-4.7*	61.1	73.7	12.7***
	(23.9)	(22.8)	(2.5)	(22.8)	(22.5)	(2.7)
Due from to total assets	8.3	5.4	-2.9***	5.4	7.0	1.6***
	(6.3)	(4.3)	(0.6)	(4.3)	(5.8)	(0.6)
Borrowing to total borrowing	14.3	32.0	17.7***	32.0	32.4	0.4
	(32.1)	(39.8)	(3.9)	(39.8)	(43.0)	(4.9)
Borrowing to total liabilities	1.1	3.6	2.5***	3.6	3.9	0.4
	(2.6)	(5.1)	(0.4)	(5.1)	(6.2)	(0.7)
Obs.	170	170		170	122	

Table C8: Geographic Interbank Deposit Network, All Banks

Due from Deposits in:	Extensive Margin (Links)			Intensive Margin (Amount)		
	1911	1920	Difference	1911	1920	Difference
New York City	19.7	14.8	-4.9***	10.8	8.7	-2.1
	(18.3)	(16.3)	(1.6)	(16.2)	(14.7)	(1.4)
Baltimore	9.7	7.4	-2.3	10.7	6.7	-4.0**
	(18.3)	(17.1)	(1.6)	(23.9)	(18.8)	(1.9)
Washington, DC	2.2	2.5	0.3	1.8	1.8	0.1
	(7.8)	(12.1)	(1.0)	(7.4)	(11.1)	(0.9)
Richmond	21.9	22.5	0.6	29.3	28.2	-1.1
	(21.1)	(25.1)	(2.1)	(32.7)	(34.0)	(3.0)
Reserve Cities in Other States	2.4	3.0	0.6	2.6	2.9	0.3
	(7.1)	(12.0)	(0.9)	(8.5)	(12.9)	(1.0)
Country Banks in VA	41.3	47.0	5.7**	40.3	49.7	9.4***
	(28.2)	(31.4)	(2.7)	(37.1)	(38.7)	(3.5)
Country Banks in Other States	2.9	2.8	0.0	3.4	1.9	-1.5
	(11.0)	(9.7)	(0.9)	(15.3)	(9.4)	(1.1)
Obs.	206	291		206	290	

C.2 Comparing 1911 to 1921

Table C9: Balance-Sheet Ratios, Virginia State Banks, 1911 and 1921

	All Banks			Both in 1911 and 1921		
	1911	1921	Difference	1911	1921	Difference
Cash to assets	4.7	2.9	-1.8***	4.7	2.8	-1.9***
	(2.9)	(2.1)	(0.2)	(2.9)	(1.7)	(0.3)
Due-froms to assets	12.7	7.2	-5.5***	12.7	6.7	-6.0***
	(7.5)	(5.7)	(0.6)	(7.5)	(5.4)	(0.7)
Bonds to assets	3.6	9.2	5.6***	3.6	11.8	8.2***
	(7.3)	(10.0)	(0.8)	(7.4)	(10.0)	(1.0)
Loans to assets	72.3	75.0	2.7**	72.4	74.5	2.1
	(13.3)	(13.1)	(1.2)	(13.9)	(12.0)	(1.4)
Equity to liabilities	25.1	20.5	-4.6***	24.6	17.7	-6.9***
	(9.2)	(10.4)	(0.9)	(8.9)	(7.3)	(0.9)
Deposits to liabilities	69.5	70.1	0.7	70.3	73.1	2.8*
	(13.2)	(15.7)	(1.3)	(12.8)	(13.5)	(1.5)
Dueto to liabilities	1.5	0.7	-0.8*	1.7	0.6	-1.1*
	(7.0)	(3.3)	(0.4)	(7.8)	(1.4)	(0.6)
Borrowing to liabilities	3.5	6.9	3.4***	3.1	6.9	3.8***
	(6.0)	(8.4)	(0.7)	(5.5)	(7.6)	(0.7)
Obs.	206	333		165	165	

Table C10: Exposures to the Largest Depository Correspondent

	Existing - Across Years			Across Banks		
	1911	1921	Difference	Existing	New	Difference
Due from to total due froms	66.0	61.8	-4.2*	61.8	74.3	12.5***
	(23.4)	(20.7)	(2.4)	(20.7)	(24.3)	(2.5)
Due from to total assets	8.3	4.2	-4.1***	4.2	5.7	1.6***
	(6.3)	(3.6)	(0.6)	(3.6)	(4.6)	(0.5)
Borrowing to total borrowing	13.9	37.7	23.8***	37.7	31.1	-6.7
	(31.8)	(85.1)	(7.1)	(85.1)	(42.3)	(7.3)
Borrowing to total liabilities	1.0	3.7	2.7***	3.7	3.8	0.1
	(2.7)	(7.7)	(0.6)	(7.7)	(6.1)	(0.8)
Obs.	165	165		165	168	

Table C11: Geographic Interbank Deposit Network, All Banks

Due from Deposits in:	Extensive Margin (Links)			Intensive Margin (Amount)		
	1911	1921	Difference	1911	1921	Difference
New York City	19.7	13.5	-6.2***	10.8	7.3	-3.4**
	(18.3)	(17.3)	(1.6)	(16.2)	(14.4)	(1.3)
Baltimore	9.7	6.4	-3.2**	10.7	7.3	-3.4*
	(18.3)	(16.2)	(1.5)	(24.0)	(20.1)	(1.9)
Washington, DC	2.2	1.9	-0.3	1.8	1.6	-0.1
	(7.8)	(10.0)	(0.8)	(7.4)	(10.3)	(0.8)
Richmond	21.9	23.6	1.7	29.3	29.7	0.4
	(21.1)	(27.6)	(2.2)	(32.7)	(35.3)	(3.0)
Reserve Cities in Other States	2.4	2.9	0.5	2.6	3.0	0.5
	(7.1)	(11.8)	(0.9)	(8.5)	(13.2)	(1.0)
Country Banks in VA	41.3	48.3	7.0**	40.3	48.5	8.2**
	(28.2)	(34.4)	(2.9)	(37.1)	(40.0)	(3.5)
Country Banks in Other States	2.9	3.5	0.6	3.4	2.2	-1.2
	(11.0)	(10.7)	(1.0)	(15.3)	(10.6)	(1.1)
Obs.	206	331		206	330	

D Robustness Using Alternative Datasets

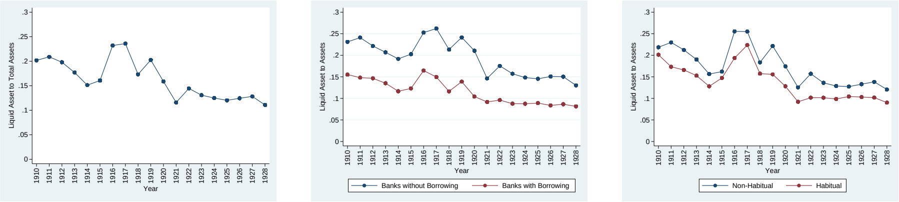
D.1 Aggregate State Bank Balance Sheet Data from Call Reports

In the main text, we provide summary statistics from the Virginia state bank balance-sheet data reported in the *Annual Report of the Banking Division of the State Corporation Commission*. Figure D12 plots the evolution of key balance-sheet ratios from 1910 to 1928. The figure shows that these ratios display irregular movements between 1914 and 1921, reflecting changes in reserve requirements and the implementation of monetary policy to accommodate World War I. For this reason, we focus on the periods 1910-1913 and 1920-1928.

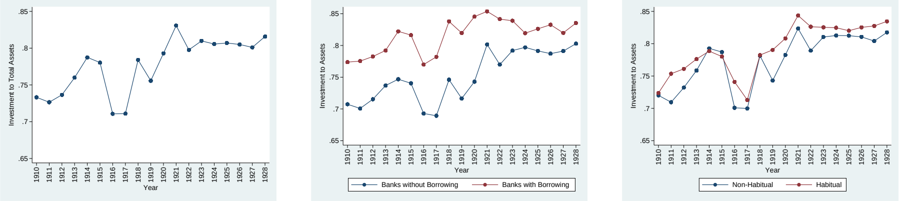
Table D12: Balance Sheet Ratios, 1910-1928

All Banks	Borrowing vs No Borrowing	Habitual vs Non-Habitual

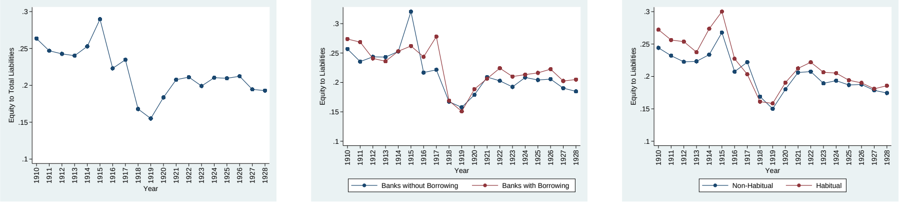
(a) Liquid Assets as Share of Total Assets



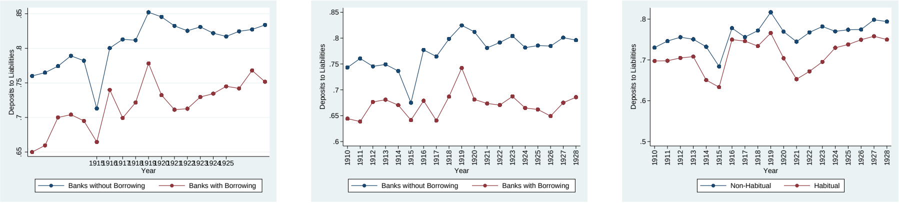
(b) Investment as Share of Total Assets



(c) Equity as Share of Total Liabilities



(d) Deposits as Share of Total Liabilities



Notes: Liquid assets include vault cash and interbank deposits. Investments are comprised of loans and bonds. Short-term borrowing is comprised of rediscounts ans bills payable.
Source: Statements Showing the Condition of the Incorporated State Banks operating in Virginia.

D.2 U.S. Aggregate Data from OCC Reports

We study changes in nonmember banks' portfolios and interbank connections by comparing 1911 (pre-Fed) with 1920, 1921, and 1922 (post-Fed). One might worry that these changes were driven by factors other than the creation of the Federal Reserve. In this section, we discuss some of these factors and address them using alternative datasets.

First, one might be concerned that Virginia is not representative of the United States. In D13, we use information from the Annual Report of the Comptroller of the Currency (OCC Reports) to document aggregate balance-sheet ratios. We focus on the periods 1910 -1913 and 1922 - 1928 to avoid the early years of the Federal Reserve System, when balance-sheet ratios displayed irregular movements. We show that the balance-sheet ratios for state banks in the United States are consistent with the corresponding ratios for Virginia nonmember banks in 2.

Table D13: Balance Sheet Ratios, U.S. Aggregate, State Banks (Percentage Points).

	1910-1913	1922-1928	Difference
Cash to assets	4.5	2.5	-2.0***
	(1.8)	(1.6)	(0.2)
Duefroms to assets	14.0	8.3	-5.7***
	(4.8)	(5.7)	(0.5)
Bonds to assets	11.3	17.8	6.6***
	(10.1)	(10.7)	(0.9)
Loans to assets	62.8	61.1	-1.7**
	(10.2)	(9.4)	(0.9)
Equity to liabilities	20.7	13.8	-7.0***
	(5.7)	(3.2)	(0.4)
Deposits to liabilities	70.9	78.3	7.3***
	(9.1)	(6.3)	(0.7)
Duetos to liabilities	3.0	2.6	-0.5**
	(2.2)	(2.2)	(0.2)
Borrowing to liabilities	2.3	3.0	0.7***
	(3.2)	(2.8)	(0.3)
Obs.	192	336	

Source: Annual Report of the Comptroller of the Currency.

Second, the observed changes in bank balance sheets might reflect differences in the business cycle or seasonal timing of the examination reports conducted by Virginia regulators. To verify that our results are not driven by these factors, we collected individual bank call reports from the *Annual Report of the Banking Division of the State Corporation Commission* covering 1910–1928. Banks were required to submit call reports to the Virginia State Banking Department on four specific days per year, and regulators published the balance sheets from the latest call in the Annual Report. In Table 2, we show the composition of bank balance sheets for the full sample and for a subset of banks present both before and after the Fed's creation (to alleviate concerns that changes might be driven by expansion in the banking sector). In both cases, these results are consistent with those derived from examination reports. On the liability side, banks increased short-term borrowing, while on the asset side, they reduced liquid assets and investments.[25]

Table D14: Balance Sheet Ratios, Virginia State Banks (Percentage Points)

	All Banks			Both periods		
	1910-1913	1922-1928	Difference	1910-1913	1922-1928	Difference
Liquid Assets to assets	19.6	12.6	-7.0***	20.0	12.1	-7.9***
	(11.4)	(7.8)	(0.4)	(11.1)	(6.8)	(0.4)
Investments to assets	73.9	80.6	6.7***	74.1	82.8	8.7***
	(13.1)	(10.6)	(0.5)	(12.7)	(7.3)	(0.5)
Equity to liabilities	24.8	20.4	-4.4***	23.2	17.2	-6.0***
	(12.2)	(12.4)	(0.5)	(10.5)	(5.8)	(0.4)
Deposits to liabilities	71.7	74.4	2.8***	74.0	78.9	4.9***
	(13.9)	(17.4)	(0.7)	(11.8)	(8.8)	(0.5)
Borrowing to liabilities	2.8	3.4	0.5**	2.5	3.2	0.7***
	(5.1)	(6.0)	(0.2)	(4.6)	(5.1)	(0.3)
Obs.	968	2223		672	1140	
Number of Banks.	284	363		171	171	

Source: Virginia State Bank Call Reports.

Third, one might be concerned that the shift in bank portfolio composition after the Federal Reserve's inception stemmed from regulatory adjustments rather than public liquidity provision. While the Federal Reserve Act and Virginia state regulations left capital requirements and branching restrictions largely unchanged, both authorities lowered reserve requirements-the Federal Reserve in 1917 and Virginia regulators in 1915. To control for this, we again utilize data from the *Annual Report of the Comptroller of the Currency* to exploit state-level variations in reserve requirements.[26]

We subsequently demonstrate that the reduction in liquid assets cannot be attributed solely to the lowering of reserve requirements for either members or nonmembers.[27] Furthermore, while changes in reserve requirements might influence cash reserves and interbank deposits,

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[25] Starting in 1920, call reports ceased to distinguish between cash assets and interbank deposits on the asset side of the balance sheet; therefore, we cannot observe the behavior of interbank deposits after the founding of the Fed using these reports.

[26] The *Annual Report of the Comptroller of the Currency* provides aggregated balance sheet data for national and state banks separately. We collected this data for 1910-1928, focusing on state banks as proxies for nonmember banks, given that their Federal Reserve membership rate remained low (on average, only 4% of state banks had joined the Fed by 1922).

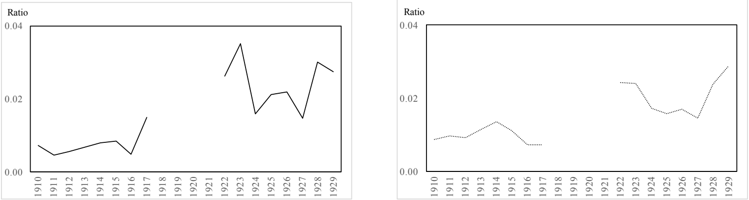
[27] This result aligns with Carlson and Wheelock (2018b) and Carlson and Wheelock (2018a).

their impact on short-term borrowing remains less clear. In Figure D5, we plot balance sheet ratios from 1910 to 1928, illustrating that in the 1920s, short-term borrowing increased as liquid assets declined.

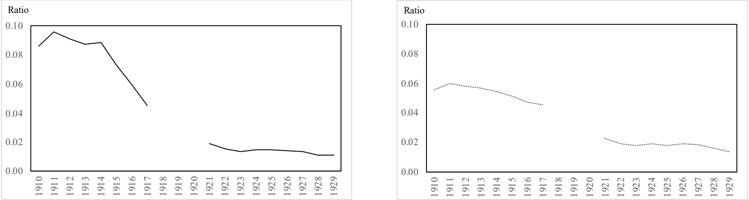
Figure D5: Aggregate Balance Sheet Ratios, 1910-1928

National Banks State Banks

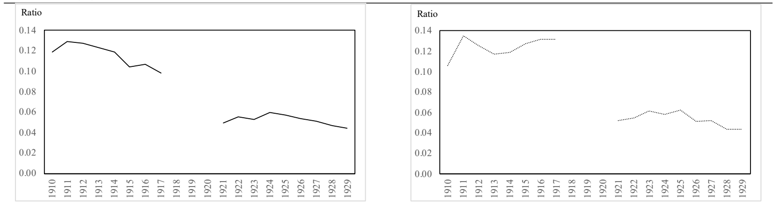
(a): Short-Term Borrowing as Share of Total Liabilities



(b): Vault Cash as Share of Total Bank Assets



(c): Deposits due from other banks as Share of Total Bank Assets



(d): Deposits due to other Banks as Share of Total Bank Liabilities

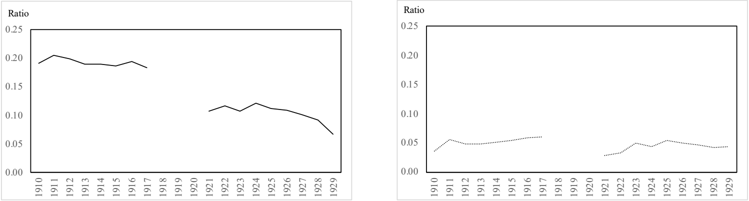


Figure D5 plots the ratio of short-term borrowing to total liabilities for national and state banks. All data are aggregated by the OCC: data for national banks are aggregated across all states, 17 reserve cities, and 3 central-reserve cities; data for state banks are aggregated across all states, all reserve cities, and reserve cities.
Source: *Annual Report of the Comptroller of the Currency*.

In addition, we check the robustness of our findings by restricting the data in two dimensions. First, we restrict our sample using state bank participation rate, as states with financial and manufacturing sectors displayed a higher proportion of state bank membership than agricultural states. Given the irregular geographic distribution of membership, one might be concerned that the described changes were generated by state member banks and that therefore our classifying all state banks as nonmembers clutters the analysis. To alleviate this concern, we restrict our sample and compare the asset composition of member and nonmember banks only in states where the membership ratio of state banks was under 10% in 1920.

Second, we restrict our sample using state-level reserve requirements. Because shifts in bank liquidity might reflect regulatory adjustments rather than voluntary portfolio management, we categorize states into three groups: (1) states that decreased their reserve requirements, (2) states that increased them, and (3) states that maintained them unchanged. Between 1910–1929, 22 states reduced requirements, 10 states increased them, and 16 states kept requirements unchanged.[28]

For states where the state bank participation rate was below 10%, Figure D6 plots the fraction of total assets that state banks in those states held in borrowing, cash, and interbank deposits. In all cases, regardless of changes in reserve requirements, nonmember banks reduced cash and interbank deposits and increased borrowing after the Federal Reserve's inception in 1914.

To summarize, we find that the Federal Reserve's existence reduced liquidity (in the form of cash and interbank deposits) and intensified interbank relations (through higher short-term borrowing) for both member and nonmember banks. Furthermore, member banks significantly reduced their relations with other member banks, but not with nonmember banks. These factors suggest less private cross-insurance but continued exposure to withdrawals, which contributed to the potential for greater systemic contagion and financial vulnerability.

In conclusion, our analysis of bank examination reports provides new evidence that the presence of the Fed fundamentally altered the role and structure of the interbank system. The ability of nonmember banks to borrow from member banks enabled them to reduce their holdings of liquid assets, including interbank deposits. Furthermore, the capacity to access credit from local member banks reduced the necessity of maintaining interbank balances in major financial centers, thereby shifting interbank relationships toward more localized networks. These findings, which are consistent across both bank-level and aggregate-level datasets covering a longer time horizon, demonstrate a structural shift in liquidity management and the broader interbank market.

D.3 Interbank Network Changes in Kansas

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[28] See White (2014) for information on state reserve requirements. We classify CA, DE, GA, IN, KS, KY, LA, MI, MN, MT, NM, NY, OK, OR, PA, SD, TX, WA, WI, WV as states with decreasing reserve requirements. In addition, we classify AR, CO, IA, MD, MS, NH, SC, TN, VT, WY as states with increasing reserve requirements. Last, we classify AL, CT, FL, ID, IL, MA, ME, MO, NC, ND, NE, NJ, NV, OH, UT as states that did not change reserve requirements.

Figure D6: Bank Liquidity and Changes in State-Level Reserve Requirements, 1910-1928

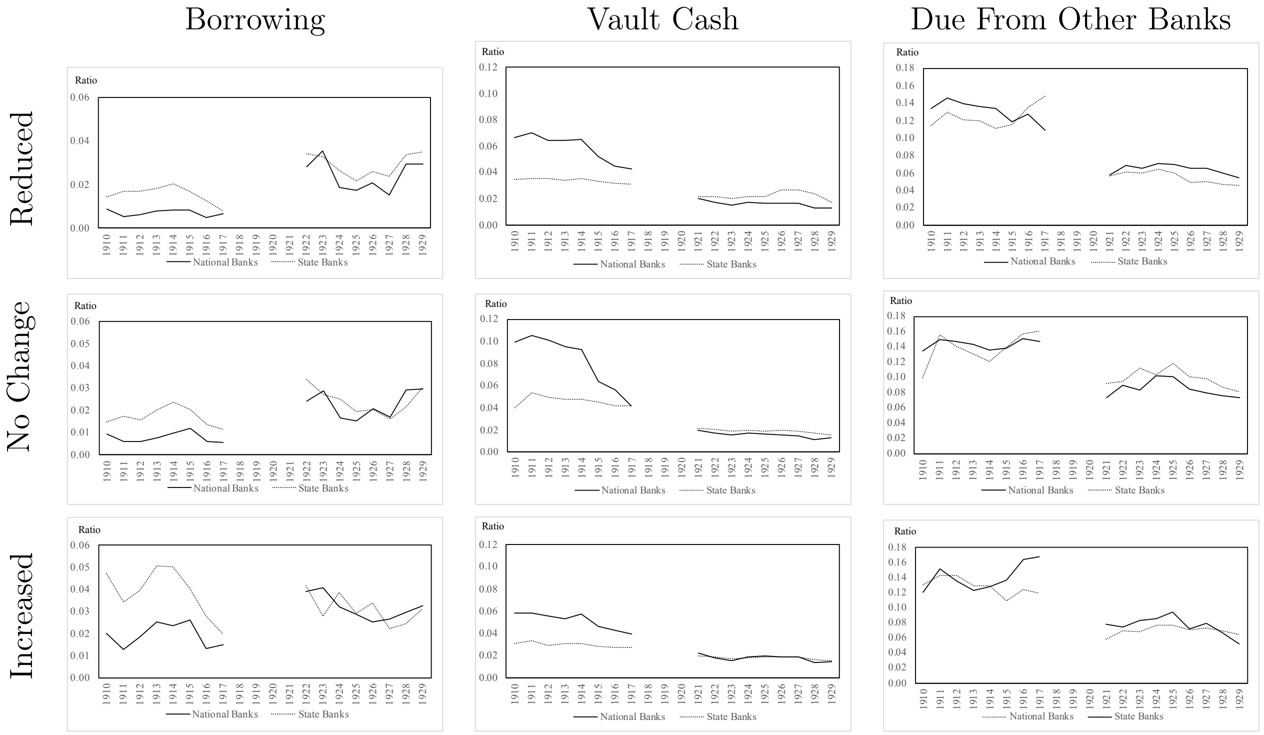

Figure D6 the share of short-term borrowing against total liabilities, the share of vault cash against total assets, and the share of deposits due from other banks against total assets for states with different reserve requirements. Data are further restricted for states where the Federal Reserve membership ratio of state banks was under 10% in 1920. All data are aggregated by the OCC: data for national banks are aggregated across all states, 17 reserve cities, and 3 central-reserve cities; data for state banks are aggregated across all states, all reserve cities, and reserve cities.
Source: *Annual Report of the Comptroller of the Currency*.

Table D15: Number of Banks in Kansas, by Bank Status

1910				1920			
Reserve City Banks		Country Banks		Reserve City Banks		Country Banks	
National	State	National	State	National	State	National	State
9	28	198	826	11	46	241	1044

Table D15 shows the number of banks for indicated groups in 1910 and 1920.
Source: *Biannual Report of the Bank Commissioner of the State of Kansas.*

Table D16: Distance between Respondent and Correspondent Banks

	1910		1920	
	Reserve City Banks	Country Banks	Reserve City Banks	Country Banks
Longest distance	1895.9	1543.6	1883.8	1303.6
	(221.7)	(747.6)	(279.1)	(845.0)
Shortest distance	44.17	113.3	27.33	91.31
	(76.13)	(124.3)	(69.54)	(110.7)
Mean distance	592.4	561.4	551.7	433.1
	(171.4)	(286.8)	(215.1)	(260.9)
Median distance	214.2	310.2	234.8	245.0
	(268.6)	(261.0)	(258.4)	(189.5)
Total distance	3015.4	2322.4	3265.1	2191.8
	(1552.2)	(1300.9)	(1503.8)	(1553.3)
Obs.	106	2730	131	3166

Table D16 provides information on geographical distances between respondent and correspondent banks in kilometers. It shows that the presence of the Fed led banks to choose correspondents located in close geographic proximity.
Source: *Biannual Report of the Bank Commissioner of the State of Kansas.*

E Implementation of the quantitative exercise

This appendix describes the numerical procedure underlying the quantitative exercise in Section 6. We implement this exercise in Matlab using a routine designed to compute both the calibrated and optimal allocations in a manner that remains stable in the presence of non-smooth choice rules, endogenous corners, and bounded parameters. To achieve this, the implementation combines moment matching, nested grid search, parameter transformations, and penalty methods.

For each candidate pair (m, ϕ), the code solves bank x's static portfolio problem. Given a portfolio, the code computes the survival probability of bank x's project and of bank y's

Table D17: Interbank Network, Kansas State Banks, 1910 and 1920.

	1910			
	Reserve City Banks		Country Banks	
	Number	Percentage	Number	Percentage
New York	24	22.64	491	17.99
Chicago	9	8.49	109	3.99
St. Louis	6	5.66	97	3.55
Kansas City	42	39.62	1,141	41.79
Topeka	4	3.77	57	2.09
Wichita	15	14.15	109	3.99
Other reserve cities	2	1.89	13	0.48
Country banks in Kansas	3	2.83	535	19.6
Country banks in other states	1	0.94	178	6.52

	1920			
	Reserve City Banks		Country Banks	
	Number	Percentage	Number	Percentage
New York	27	20.61	384	12.13
Chicago	8	6.11	73	2.31
St. Louis	7	5.34	39	1.23
Kansas City	63	48.09	1,404	44.35
Topeka	7	5.34	118	3.73
Wichita	11	8.4	242	7.64
Other reserve cities	4	3.05	14	0.44
Country banks in Kansas	1	0.76	708	22.36
Country banks in other states	3	2.29	184	5.81

Table D17 provides information on the number of links each city received from reserve city and country banks in Kansas. New York, Chicago, and St. Louis were central reserve cities. Kansas City, Topeka and Wichita were reserve cities in Kansas. Kansas city data is aggregated across Kansas City, KS and Kansas City, MO. The linkage data is aggregated across these cities and used to calculated the proportion of links in each city.

Source: *Biannual Report of the Bank Commissioner of the State of Kansas.*

project, and then evaluates bank x's expected profit as

$$\Pi_x = \Gamma\, r_x I_x + \Delta\, r L, \tag{E1}$$

The planner's welfare criterion in the code is the full welfare objective

$$W(m, \phi) = \eta \Big[n\, p_x\, r_x I_x + (1-n)\, p_y\, r_y I_y \Big] - \frac{1}{2}\kappa m^2, \tag{E2}$$

where p_x and p_y denote the unconditional survival probabilities of the projects of banks x and y, respectively. Thus, every evaluation of planner welfare requires first solving bank x's problem and then feeding the resulting endogenous portfolio back into the welfare expression.

This nested structure is what makes the computation delicate. The planner's problem is not smooth in (m, ϕ) or in the induced portfolio choices, because the bank's inner problem features corners, kinks, and state-contingent survival formulas. The numerical implementation is designed specifically to address those issues.

E.1 Calibrating shock distributions and liquidation effectiveness

The first step of the program uses the pre-Fed portfolio moments to calibrate the remaining objects that determine the bank's exposure to liquidity shocks. In the implementation, this stage fixes $m = 0$ and uses the pre-Fed reserve requirement $\phi_{1911} = 0.25$. It then chooses two parameters:

1. the scale parameter θ of the truncated-Gamma shock distribution, and
2. the liquidity-effectiveness parameter λ, which discounts the contribution of interbank deposits to bank x's survival probability.

The target moments are the empirical cash and interbank-deposit shares of nonmember banks in 1911. In the code, these moments are expressed relative to deposits, so the objective matches the model-implied pair (Φ_x, L) to the pre-Fed moments.

Our objective is a weighted squared distance of the form

$$\mathcal{J}_1(\lambda, \theta) = \left(\frac{\Phi_x(\lambda, \theta) - \Phi_x^{1911}}{\Phi_x^{1911}} \right)^2 + \left(\frac{L(\lambda, \theta) - L^{1911}}{L^{1911}} \right)^2 . \tag{E3}$$

Normalizing by the target values is a practical choice: it places the two moments on a comparable scale so that the objective is not mechanically dominatedby whichever target happens to be numerically larger.

For stability reasons, the code does not optimize directly over (λ, θ), because these parameters are naturally constrained:

$$0 < \lambda < 1, \qquad \theta > 0. \tag{E4}$$

Instead, the code optimizes over unconstrained variables $(x_1, x_2) \in \mathbb{R}^2$ and maps them into the admissible set through

$$\lambda = \frac{1}{1+e^{-x_1}}, \qquad \theta = e^{x_2}. \tag{E5}$$

This matters because the optimizer used throughout the program,`fminsearch`, is an unconstrained routine. Working with transformed variables eliminates the need for explicit constraints and prevents pathological evaluations in which the optimizer attempts negative values for scale parameters or values of λ outside the unit interval.

A second numerical device is that the code precomputes the truncation denominator of the incomplete gamma function,

$$\texttt{denom} = \texttt{gammainc}(Z/\theta, k, \texttt{'lower'}), \tag{E6}$$

and then passes this object to every function that evaluates the truncated distribution. This is purely computational but highly useful: the survival function is evaluated thousands of times inside nested loops, so recomputing the same denominator at every call would be unnecessarily costly.

Finally, the code includes a penalty when the denominator becomes numerically too small or non-finite. In that case, the objective returns a large value, forcing the optimizer back into the admissible region. This is a standard but important safeguard: the gamma truncation can become unstable for extreme parameter guesses, and it is better to penalize those evaluations than to allow the optimizer to continue with invalid objects.

Our brute-force grid search is slower than a derivative-based method, but it is substantially more robust in the present environment. The bank's payoff is not globally differentiable: survival probabilities are piecewise-defined, depend on indicator conditions, and can generate endogenous corners in the optimal portfolio. In such settings, first-order conditions are not reliable global characterizations, and local methods can jump across kinks or settle at non-optimal corners. By contrast, the grid search remains well-behaved.

The code also incorporates a small implementation refinement: for each given L, the resolution of the grid over I_x is scaled to the length of its feasible interval $[0, D-L]$. This ensures that the search remains reasonably fine even when the feasible set for I_x becomes small. This adjustment improves accuracy without causing thethe total number of grid points to explode.

The truncated-Gamma distribution is coded piecewise: The function `S_mix_fast` implements the distribution function used for liquidity shocks. In the paper, the shock distribution is a truncated Gamma distribution. In the program, this object is coded as a mixture with explicit boundary handling: for arguments below zero, the function is set to zero; for arguments above the upper support D, it returns one; and for interior points it evaluates the truncated incomplete gamma function.

There are two reasons for this piecewise implementation. First, it is economically correct: the support of the distribution is bounded. Second, it is numerically safer. Rather than relying on the incomplete gamma function to behave well near all boundaries, the code imposes the known values directly. This sharply reduces numerical noise around the edges of the support, which matters because small perturbations near the threshold can change which portfolio point appears optimal on a grid.

E.2 Calibrating post-Fed public liquidity and shock exposure

The second stage uses the post-Fed portfolio moments. In the code, the reserve requirement is fixed at the observed 1922 value, $\phi_{1922} = 0.13$, and then jointly calibrates

$$(\hat{m}, \alpha_y), \tag{E7}$$

where $\hat{m}$ is the amount of public liquidity reaching nonmembers and α_y is the probability that bank y experiences a withdrawal shock that reduces the liquidity available to bank x.

The target moments are again the empirical cash and interbank-deposit shares, now for 1922. The corresponding objective is

$$\mathcal{J}_2(m, \alpha_y) = \left(\frac{\Phi_x(m, \alpha_y) - \Phi_x^{1922}}{\Phi_x^{1922}}\right)^2 + \left(\frac{L(m, \alpha_y) - L^{1922}}{L^{1922}}\right)^2. \tag{E8}$$

This problem is more challenging than Stage 1 because both m and α_y affect portfolio choices through nonlinear and partially offsetting channels. A higher m increases the liquidity support to bank x, while a lower α_y makes the state in which bank y absorbs public liquidity less likely. Either force reduces precautionary holdings, so the objective can be rather flat along some directions.

To stabilize the search, the code does not begin with a purely local optimizer. Instead, it first performs a coarse grid search over a broad rectangle in (m, α_y) space and then uses the best point on that coarse grid as the starting value for `fminsearch`. This is an effective computational choice: the coarse grid is not intended to be precise, but rather to place the local optimizer in the correct basin of attraction. Without this first pass, the local search could easily converge to a poor local minimum.

As in Stage 1, the actual optimization uses transformed variables,

$$m = e^{x_1}, \qquad \alpha_y = \frac{1}{1 + e^{-x_2}}. \tag{E9}$$

which automatically enforce admissibility and prevents the optimizer from trying negative values of m or probabilities outside $(0, 1)$.

The code also adds a tiny regularization term in m. Its quantitative effect is negligible at the calibrated solution, but it helps select smaller values of public liquidity when the fit is nearly flat in one direction. In other words, the regularization acts as a numerical tie-breaker in regions where several nearby values of m match the target moments almost equally well.

E.3 Backing out the cost of public liquidity

Once $(\hat{m}, \alpha_y)$ has been calibrated, the code infers the distortionary cost of public liquidity, κ. As in Section 6, we assume that the Fed internalized only the role of public liquidity in preventing liquidation at members, not the pass-through to nonmembers. The paper then computes the total amount of public liquidity as

$$\hat{m}^b = 5\left[\alpha_y m + (1 - \alpha_y)(m - \bar{\zeta}_y)\right] = 5m - 5(1 - \alpha_y)\bar{\zeta}_y, \tag{E10}$$

and backs out κ from the condition

$$r_y I_y = \kappa \hat{m}^b. \tag{E11}$$

The code mirrors that step and computes

$$\hat{\kappa} = \frac{r_y I_y}{\hat{m}^b}. \tag{E12}$$

A practical issue arises here: if the expression for $\hat{m}^b$ becomes non-positive for a candidate calibration, the implied κ is not economically meaningful. The code therefore checks for this explicitly. If the denominator is non-positive, it sets $\kappa = \infty$ and issues a warning. This prevents subsequent welfare calculations from being driven by an invalid back-out.

E.4 Planner optimization at fixed and flexible public liquidity

After calibration, the program solves two welfare problems. In the first, it takes the calibrated level of public liquidity $\hat{m}$ as given and chooses only reserve requirements:

$$\phi^*(\hat{m}) = \arg \max_{\phi \in (0,1)} W(\hat{m}, \phi). \tag{E13}$$

In the second one, it solves the full planner problem,

$$(m^*, \phi^*) = \arg \max_{m \geq 0,\, \phi \in (0,1)} W(m, \phi). \tag{E14}$$

As before, the code uses transformed variables rather than constrained optimization. For the one-dimensional problem it writes

$$\phi = \frac{1}{1 + e^{-x}}, \tag{E15}$$

and for the joint problem it writes

$$m = e^{x_1}, \qquad \phi = \frac{1}{1 + e^{-x_2}}. \tag{E16}$$

The search therefore takes place over the unconstrained Euclidean space, while the policy variables themselves always remain in economically meaningful regions.

Another numerical choice that improves stability is the initialization of the planner problems. The optimization over ϕ begins at the empirical 1922 reserve requirement. The joint optimization over (m, ϕ) begins at the pair consisting of the Stage 2 estimate of m and the optimum $\phi^*(\hat{m})$ from the previous step. This warm start matters because welfare is costly to evaluate and not globally concave. Starting from economically relevant values reduces the likelihood that the optimizer spends many iterations exploring poor regions of the parameter space.