Unintended Consequences of Post-Crisis Liquidity Regulation*

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Abstract

We evaluate the effects of post-crisis liquidity regulations on the U.S. banking system. Although the new regulations have increased liquidity buffers held by banks, a significant fraction of those buffers has been created through "collateral transformation" facilitated by government-sponsored enterprises known as the Federal Home Loan Banks (FHLBs). Collateral transformation allows banks to meet liquidity requirements while continuing to earn high returns from illiquid assets. However, collateral transformation also compromises the goal of liquidity regulation because it increases banks' reliance on public liquidity from the FHLBs and allows illiquidity to stay in the banking system. We show that the cost of accessing public liquidity from the FHLBs must adjust in conjunction with liquidity regulations to prevent excessive liquidity transformation. However, such coordination appears to be absent in the fragmented regulatory system in the United States.

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1 Introduction

One of the key functions of the banking system is liquidity transformation, that is, funding illiquid assets using short-term debt. However, as shown in the 2007–2009 financial crisis, if left regulated, banks tend to engage in excessive liquidity transformation, which makes them vulnerable to runs. When a run occurs, the government has no choice but to inject liquidity into the system, which exposes taxpayers to substantial risk. In response to this problem, regulators introduced a new set of liquidity regulations. The goal of these regulations is to increase the banking system's liquidity buffers and to reduce its reliance on public liquidity.

Unlike capital regulation, which has received extensive academic scrutiny, liquidity regulation has run ahead of research and many important questions remain unanswered (Diamond and Kashyap, 2016; Allen and Gale, 2017). First, it is unclear how banks will cope with these new liquidity requirements because a large part of their business model is to earn a return premium by holding illiquid assets. Second, both liquidity regulations and public liquidity backstops could address liquidity risk, but it is unclear how the two policy instruments should coordinate.[1] Third, because public liquidity backstops can produce liquid assets required by liquidity regulations, it is unclear how liquidity regulations will interact with public liquidity backstops in normal times.

We address these questions by investigating the impact of liquidity regulations on the U.S. banking system. Two major components of liquidity regulation have been implemented in the United States so far. The first component is the Liquidity Coverage Ratio (LCR), which requires banks to hold enough high-quality liquid assets (HQLAs) to survive 30 days of cash outflows in a stress scenario. The second component is money market reform, which requires money market funds (MMFs) to limit liquidity provided to their investors.

Although these new regulations have increased liquidity buffers held by banks, we find that a significant fraction of those buffers has been created through "collateral transformation" facilitated by government-sponsored enterprises known as the Federal Home Loan Banks (FHLBs). The FHLBs provide low-cost liquidity to member financial institutions

[1] Public liquidity backstops usually include emergency lending programs by the central bank, such as the discount window of the Federal Reserve. However, some government-sponsored enterprises, such as the FHLBs, may also act as a public liquidity backstop in times of crises (Ashcraft, Bech, and Frame, 2010).

to support housing finance and community investment.[2] Small banks used to be the main borrowers from the FHLBs because they did not have alternative funding sources. However, after the roll-out of liquidity regulations, big banks, which are subject to tight liquidity requirements, started to use the subsidized liquidity from the FHLBs to conduct "collateral transformation."

The process of "collateral transformation" is illustrated in Figure 1. To finance liquidity buffers required by the regulations, banks could reduce illiquid asset holdings. However, this approach would lower banks' asset returns. Alternatively, banks could pledge their illiquid assets to the FHLBs in exchange for liquid assets. By doing so, banks would be able to meet liquidity requirements while continuing to earn high returns from illiquid assets. However, collateral transformation also compromises the goal of liquidity regulation because it increases banks' reliance on public liquidity from the FHLBs and allows illiquidity to stay in the banking system.

Using a comprehensive database on banks, FHLBs, and MMFs, we document a massive expansion of collateral transformation in the U.S. banking system after liquidity regulations were introduced. On the demand side, we show that the LCR increases banks' demand for collateral transformation. Specifically, by exploiting the differences in banks' exposure to liquidity regulations due to bank size and pre-regulation liquidity position, we find that banks that are more exposed to liquidity regulations increase their borrowing from the FHLBs by a larger amount. Furthermore, banks use the borrowed funds to build up liquidity buffers rather than to finance housing investment as the mission of the FHLBs intended.

On the supply side, the other major component of the post-crisis liquidity regulation, money market reform, facilitates collateral transformation by increasing the funding supply from MMFs to the FHLBs. Money market reform shifted deposits from prime MMFs, whose assets were primarily private debt, to government MMFs, who could only invest in government or agency securities. By exploiting the pre-reform differences in the fraction of prime fund assets within each fund family, we find that the fund families more exposed to the reform have substantially increased their lending to the FHLBs. In aggregate, lending from MMFs to the FHLBs *quadrupled* since the reform took effect and the FHLBs increasingly fund themselves using shorter-term debt with an average maturity of less than 40 days. The increasing funding supply from MMFs to the FHLBs further lowers the cost

[2]Section 3 provides a detailed description on these institutions.

of collateral transformation for banks, but it also introduces fragility as the investors of MMFs can redeem at any time.

Taken together, the post-crisis liquidity regulations have led to a massive expansion of collateral transformation via the FHLBs: the LCR increases the demand for collateral transformation while money market reform increases the supply. Based on our estimates, 30% of the liquidity buffer is created by collateral transformation through the FHLBs. As a result, the balance sheets of the FHLBs rapidly expanded by nearly 50% from 2012 to 2017 and reached $1.1 trillion.

We develop a model of liquidity regulation to understand the causes and implications of collateral transformation. We introduce the institutional feature that banks have access to public liquidity backstops such as the Federal Reserve's discount window or the FHLBs to the canonical model of Diamond and Kashyap (2016). While public liquidity backstops are designed to provide emergency liquidity in stress times (the Fed's discount window) or promote housing investment (FHLBs), we show that they could be used by banks to transform collateral to meet liquidity regulations. The amount of public liquidity used to transform collateral depends on the tightness of the regulation and the cost to access public liquidity backstops. If the cost to access public liquidity backstops is high, as is the case for the Fed's discount window, tightening liquidity regulations will not affect the use of public liquidity. However, if the cost to access public liquidity backstops is low, as is the case for the FHLBs, tightening liquidity regulations will increase the amount of public liquidity used to transform collateral.

Our model illustrates four potential implications of collateral transformation for liquidity regulation. First, such transactions allow banks to meet liquidity requirements without reducing the amount of liquidity transformation. Second, such transactions increase banks' reliance on public liquidity backstops, which is inconsistent with the goal of liquidity regulation. Third, such transactions encumber banks' balance sheets, which increases potential losses of other creditors when banks default. Fourth, if these transactions are based on rolling short-term debt contracts, the resulting liquidity buffer may not be resilient in times of stress.

A key insight of our model is that any liquidity regulation must also simultaneously address the way in which public liquidity is priced. However, we find that coordination among different policy instruments implied by our model is absent in the data: the cost of borrowing from FHLBs remained unchanged or even fell since the roll-out of liquidity reg-

ulations, which has resulted in the expansion of collateral transformation via the FHLBs. We argue that regulatory fragmentation is the reason for the lack of coordination. In the United States, financial regulation is divided among separate regulatory agencies with different mandates.[3] In our context, the regulator of the FHLBs did not raise the cost of borrowing from the FHLBs in conjunction with liquidity regulation because it views lending to banks as part of their mandate to promote housing investment. However, in reality, such funding is mainly used by large banks to fulfill liquidity requirements. The regulators of commercial banks treat the FHLBs as stable sources of funding without necessarily recognizing that the FHLBs themselves are largely financed by unstable funding.[4] The regulator of MMFs aims to improve liquidity and safety of MMFs but has unintentionally made the funding structure of the FHLBs more fragile. In such a fragmented regulatory system, each regulator focuses on their narrowly defined mandates without considering the broader consequences on the other parts of the banking system. This lack of coordination ultimately allows financial institutions to use public liquidity to meet their liquidity requirements.

Finally, we use the model to study potential policy remedies. The first approach would impose strict leverage requirements on the FHLBs. We show, however, that leverage requirements may be ineffective because of a unique institutional feature of the FHLBs, known as activity-based capital, which allows the FHLBs to obtain capital automatically when they lend to banks. The second and third approaches would tighten the collateral requirement or adjust the regulatory treatment of the run-off rates of FHLB funding in the calculation of banks' LCR. The downside of these two approaches is that they may lead to high compliance costs if liquid assets are scarce in the economy. The last approach would use a price-based mechanism similar to the Committed Liquidity Facility (CLF) used in Australia. In this approach, banks pay commitment fees to obtain loan commitments from public liquidity backstops. Regulators set the commitment fees to reflect the social cost of supplying public liquidity and count the *unused* loan commitments as HQLAs in the LCR. We show such a price-based mechanism produces the optimal outcome in our model in which the use of public or private liquidity is contingent on the scarcity of liquid assets in the economy.

[3]Commercial banks are primarily regulated by the Federal Deposit Insurance Corporation (FDIC), the Federal Reserve Board, or the Office of the Comptroller of the Currency (OCC). MMFs are regulated by the SEC. The FHLBs are regulated by the Federal Housing Finance Agency (FHFA).

[4]Borrowing from the FHLBs has low "run-off" rates in the LCR calculation. The "run-off" rates are expected rates of draw-down for each category of bank liabilities in a stress scenario.

The rest of the paper is organized as follows. In Section 2, we discuss the related literature and our contribution. In Section 3, we describe the institutional background. In Section 4, we develop a model of liquidity regulation to lay out the conceptual framework. In Section 5, we present empirical evidence on how liquidity regulations lead to collateral transformation. In Section 6, we discuss potential policy remedies. Section 7 concludes.

2 Related Literature

In this section, we review the relevant literature and summarize our paper's contributions. First, our paper contributes to the literature on liquidity regulation. Unlike capital regulation, which has received extensive academic scrutiny, liquidity regulation is only beginning to attract academic investigation (Allen and Gale 2017). A number of recent theory papers have focused on how liquidity requirements affect bank runs. Calomiris, Heider, and Hoerova (2015) provide a theory of liquidity regulation based on the idea that it is much easier to verify the value of liquidity than other types of capital. Diamond and Kashyap (2016) argue that liquidity regulation can reduce the probability of a run. We contribute to this literature by analyzing the interaction between liquidity regulation and public liquidity backstops, an issue emphasized by Stein (2013) in a speech at the Federal Reserve Bank of Richmond. We show that any bank liquidity regulation must also simultaneously address the way in which government-supplied liquidity is priced. A lack of coordination from the pricing of public liquidity will compromise the effectiveness of liquidity regulation to reduce excessive liquidity transformation. Buiter (2009) and Allen, Carletti, and Gale (2014) argue that forcing private institutions to hold liquidity may not be socially optimal because the central bank can always create liquidity in a crisis. In contrast, Stein (2013) argues that the use of public liquidity could be socially costly as well because lending to troubled banks exposes taxpayers to credit risk and encourages future moral hazard. We show that whether public or private liquidity should be used to address liquidity risks depends on the relative magnitude of liquidity premium and the social cost of supplying public liquidity. We further show that a price-based mechanism used by Australia's central bank can implement the socially optimal outcome.

Our paper also relates to a growing body of empirical literature on liquidity regulation. Hoerova, Mendicino, Nikolov, Schepens, and Van den Heuvel (2018) and Berger, Black, Bouwman, and Dlugosz (2017) show that during the 2007-09 crisis, banks with higher

liquidity ratios were less likely to borrow emergency liquidity from the Federal Reserve or the ECB. Note that these papers predate the implementation of liquidity regulation and their findings are based on liquidity buffer voluntarily held by banks. In contrast, our paper evaluates the post-crisis period in which banks are mandated to increase their liquidity buffer. We find that a large fraction of liquidity buffer is borrowed from the FHLBs to meet the regulations. Such regulatory arbitrage suggests that the mandated liquidity buffer may not be as effective in reducing liquidity risk as before. Our paper is also related to a strand of research on the measurement of liquidity position of the banking system (Berger and Bouwman, 2009; Bai, Krishnamurthy, and Weymuller, 2018). We show that the current liquidity coverage ratio is gamed by banks because the run-off rates of banks' funding only depends on the direct lenders (the FHLBs) instead of the ultimate funding source (MMFs).

Our paper relates to the literature that studies the role of the FHLBs in the financial system. Flannery and Frame (2006) is one of the early studies on the risk-taking incentive of FHLBs. Ashcraft, Bech, and Frame (2010) highlight the role of the FHLB system in extending liquidity to banks during the 2007–2009 financial crisis. Gissler and Narajabad (2017) and Anadu and Baklanova (2017) document aggregate trends of the FHLBs' balance sheets in the post-crisis period amid the roll-out of the Basel III liquidity requirements and money market reform. While these two papers focus on the potential vulnerabilities of the FHLBs such as counterparty risk and rollover risk, our paper is the first to study the implications of the FHLBs for liquidity regulations. We show that collateral transformation provided by the FHLBs compromises the effectiveness of liquidity regulation. In addition, our paper provides systematic evidence supporting the hypothesis that liquidity regulations indeed drive the expansion of the FHLBs by exploiting the cross-section variation in regulatory exposure.

Our paper adds to a growing body of literature on the effect of money market reform. McCabe, Cipriani, Holscher, and Martin (2013) and Hanson, Scharfstein, and Sunderam (2015) systematically evaluate different money market reform proposals. Cipriani, La Spada, and Mulder (2017) use money market reform as a quasi-natural experiment to estimate the convenience of having stable Net Asset Values (NAVs). Narajabad and Gissler (2018) exploit this episode to study the crowding out of traditional banks' supply of safe assets by shadow banks. Baghai, Giannetti, and Jäger (2017) study how the reform has changed the risk-taking behavior for the prime money market funds. Our paper shows that the 2016 money market reform unintentionally funnels extensive amounts of

short-term funding to FHLBs. This, in turn, enables FHLBs to lend to banks to meet their liquidity requirements. More broadly, our paper also contributes to the literature on the systemic risks of MMFs (Kacperczyk and Schnabl 2013; Chernenko and Sunderam 2014; Schmidt, Timmermann, and Wermers 2016; La Spada 2018).

Finally, our paper contributes to the literature on the design of financial regulations. The recent financial crisis has led to a substantial surge in interest in this area. Most of the debate has been about which financial activities should be regulated, while the discussion on reforming the regulatory structure itself has been less active (Agarwal, Lucca, Seru, and Trebbi 2014). Our paper studies the regulatory structure in the context of liquidity regulations. In our theoretical model, we show that effective regulation requires coordination between liquidity requirements and pricing of public liquidity. However, such regulatory coordination appears to be absent in the fragmented regulatory system in the United States because these policies are managed by different regulators. We show that such regulatory fragmentation may have large welfare consequences for the economy.

3 Institutional Background

3.1 Post-Crisis Liquidity Regulations

The first post-crisis liquidity regulation that we examine is the Liquidity Coverage Ratio requirement (LCR). The LCR was initially proposed by the Basel Committee on Banking Supervision in December 2010 and finalized in January 2013 as a part of the Basel III regulatory framework. In the United States, the Federal Reserve carried out its first ever system-wide stress test of bank liquidity for the largest U.S. banks in November 2012, which marked the beginning of liquidity regulation in the United States. The LCR mandates that banks with at least $250 billion in total assets or at least $10 billion in on-balance sheet foreign exposure hold enough HQLA, defined as cash, central bank reserves, Treasuries, and certain types of agency mortgage-backed securities, to cover expected net cash outflow for a 30-day stress scenario. The goal of the LCR was to curb banks' excessive liquidity transformation and reduce their reliance on the public liquidity backstop in stressed times.[5]

[5]The other key component of Basel III liquidity standards is the Net Stable Funding Ratio (NSFR) requirement, which is intended to ensure that banks have a robust funding profile over a one-year horizon. The NSFR has not been implemented in the United States as of 2018.

The second main liquidity regulation that we examine is the 2016 money market reform. MMFs transform money market instruments with maturities ranging from several months to one year into daily liquidity. During the crisis, the Reserve Primary Fund "broke the buck", which triggered a massive run on the MMF industry. In 2014, the SEC adopted a set of new liquidity regulations on MMFs, including redemption fees, redemption gates, and floating NAV requirements, with an implementation deadline of October 2016. The money market reform mainly affected the prime funds, which hold private debts; government funds are exempted from some of the most stringent regulations such as the floating NAV requirement.

3.2 The Federal Home Loan Bank System

The FHLB system, which was established in 1932, is a large government-sponsored enterprise (GSE) whose mission is to assist its member financial institutions to finance housing and certain types of community development lending. Membership in the FHLB is voluntary and restricted to federally insured depository institutions, insurance companies, and Community Development Financial Institutions (CDFIs). As of June 2018, the FHLB system has 11 regional banks and over 6,900 members. The collateralized loans that the FHLBs provide to banks are called "advances" and their maturities range from overnight to 30 years.[6]

During the 2007–2009 financial crisis, the FHLBs became an important provider of liquidity to banks in first half of 2007 because they offered "stigma-free" funding with favorable pricing compared to the discount window of the Federal Reserve. However, the FHLBs' lending to banks also drew sharp criticism because the loans often had weak collateral standards and were concentrated in big banks (Gaberlavage 2017).[7] Following heightened concerns about the financial health of Fannie Mae and Freddie Mac in the second quarter of 2008, the FHLB system found itself "guilty by association" and saw its borrowing costs and advance rates rise (Ashcraft, Bech, and Frame 2010). In response to these problems, the 2011 joint report by the Department of Treasury and HUD recom-

[6]We provide a more detailed description of the key institutional features of the FHLB system In the Appendix.

[7]For example, Senator Charles Schumer criticized advances made to Countrywide Bank by the FHLB of Atlanta stating that the bank was serving as Countrywide's "personal ATM." Based on a study by the Federal Housing Finance Agency (FHFA), 34.5% of the collateral was subprime, nontraditional, or Alt-A loans at the end of 2007.

mended limiting the level of advances and reducing portfolio investments of the FHLBs as part of the broad housing market reform.[8]

4 Model

In this section, we introduce the institutional feature that banks have an access to public liquidity backstops such as the central bank discount window and the FHLBs into the Diamond and Kashyap (2016) model of liquidity regulation. We keep the framework sparse to develop sharp predictions and hypotheses for our empirical tests.[9] We have three goals for this model: First, we want to understand how changes in liquidity regulations might affect banks' demand for public liquidity. Second, we want to study how the cost of public liquidity should be adjusted to prevent banks from using it to meet liquidity regulations. Third, we want to explore how the predictions of canonical banking models such as Diamond and Kashyap (2016) concerning the effectiveness of liquidity buffers in mitigating the risk of runs may be affected by the way that the liquidity buffer is financed.

4.1 Setting

There are three dates, $T = 0$, 1, and 2. For a unit investment at date 0, the bank offers a demand deposit that can be redeemed either at date 1 or at date 2. For simplicity, the time lapse between date 0 and 1 is infinitely small so there is no accrued interest at date 1. Therefore, the redemption value is 1 at date 1 and r at date 2. The bank can invest in two assets with constant returns to scale. One is a liquid asset that generates a $R_1 > 1$ at date 2. The other is an illiquid asset that generates a return of $R_2 > R_1$ at date 2. The early liquidation value is 1 for liquid assets and 0 or illiquid assets.[10] A higher liquidity premium, $R_2 - R_1$, reflects a greater scarcity of the liquid asset. At date 0, the bank decides the asset composition. q is the quantity of liquid assets and $1 - q$ is the quantity of illiquid assets. As $1 - q$ units of illiquid assets are transformed into 1 unit of liquid deposits, $1 - q$ also measures the extent of liquidity transformation in the economy.

[8] Reforming America's Housing Finance Market: A Report to Congress, February (2011), U.S. Department of Treasury and the Department of Housing and Urban Development.

[9] We abstract away capital regulation as it has been extensively studied in the prior literature. Kashyap, Tsomocos, and Vardoulakis (2017) propose a model that studies the interaction between liquidity and capital regulation.

[10] The results are robust to any positive liquidation value less than 1 for the illiquid assets.

There are two states of the world, $s = G, B$, which realize at date 1 with a probability of $1 - p$ and p respectively. In the good state, G, no depositors want to withdraw early. In the bad state, B, a fraction Δ of depositors want to withdraw early. Define f_s as the amount of early withdrawals in state s. If the liquidity buffer is less than the early withdrawals, $q < f_s$, then a bank run will occur and the bank will be insolvent.

4.2 Equilibrium in a Laissez-Faire Economy

We first consider a laissez-faire economy in which banks do not have access to public liquidity backstops and do not face liquidity regulation. At date 0, the bank chooses the amount of liquid assets and illiquid assets to maximize the equity value.

$$\max_q \mathbb{E}\left[\left((1-q)\,R_2 + (q - f_s)R_1 - (1 - f_s)r\right)\mathbb{1}_{[q \geq f_s]}\right]. \tag{1}$$

where $\mathbb{1}_{[q \geq f_s]}$ is an indicator function that takes a value of one if the bank has enough liquidity to cover the early withdrawals, and zero otherwise. If the available liquidity is lower than the early withdrawals, a bank run will occur, which leads to a large externality, L, to the rest of the economy. The social welfare is the following

$$\mathbb{E}\left[(1-q)\,R_2 + (q - f_s)R_1 - \mathbb{1}_{[q \geq f_s]}L\right]. \tag{2}$$

If the social cost of the run L is large enough, it is socially optimal to prevent runs in both states. However, the shareholders of the bank do not internalize the social cost of bank run, L, because they are protected by limited liability in the event of bankruptcy. Therefore, the privately optimal liquidity buffer is too low to prevent socially costly bank runs. In another words, there is excessive liquidity transformation in the economy. Formally, if the following condition holds, the bank chooses to hold no liquidity $q = 0$, and bank runs occur in the bad state.

$$(1 - \Delta)R_2 + (1 - p)\Delta R_1 - (1 - p\Delta)r < (1 - p)(R_2 - r). \tag{3}$$

When the liquid asset becomes more scarce (lower R_1), the bank is more likely to hold no liquidity and let bank runs occur in the bad state.

4.3 Equilibrium with Government Interventions

Now we introduce public liquidity backstops and liquidity regulation into the economy. The bank can pledge b units of illiquid assets to the public liquidity backstop to borrow $b\lambda$ units of liquid assets, where λ is the collateral value of the illiquid assets and $1 - \lambda$ is the haircut.[11] Note that the bank can access the public liquidity backstop at date 0 before the state is realized or at date 1 contingent on state s. We define b_0 and b_s as the units of illiquid assets pledged to the public liquidity backstop at date 0 and date 1, respectively. Define c as the cost of accessing the public liquidity backstop, which includes both the interest cost and the potential stigma.[12] For now, we can think about the public liquidity backstop as the discount window of the central bank that has unlimited lending capacity. Later we consider the case of the FHLBs in which the lending capacity may be unstable and binding.[13] We also assume the bank always has enough illiquid assets as collateral and will consider a binding collateral constraint when we discuss policy remedies in Section 6.

It is clear that unlimited access to public liquidity can always prevent bank runs. However, as Stein (2013) argues, relying on public liquidity to address bank runs may be socially costly for two reasons. First, it is often impossible to differentiate illiquid banks from insolvent banks, so lending to troubled banks may expose taxpayers to large credit risks. Second, using public liquidity to support banks when they get into trouble can lead to moral hazard problems. We abstract away from specific microfoundations of the social cost of supplying public liquidity and instead use the exogenous parameter w to capture the social cost.

A high social cost of supplying public liquidity motivates preventative liquidity regulation, which requires banks to hold liquidity buffers ex ante to reduce their reliance on public liquidity. In the model, the regulator requires the bank to hold as least ρ units of liquid assets per unit of deposits at date 0. ρ is also known as the "run-off rate" of deposits

[11] The bank will not use liquid assets as collateral because LCR requires the liquidity buffer to be unencumbered.

[12] Note that the cost of public liquidity is defined as a spread over the prevailing risk-free rate in each period so the gross borrowing rates are $1 + c$ and $R_1 + c$ at date 1 and date 2 respectively.

[13] In reality, even the lending capacity of the discount window could also be binding due to the insufficiency of eligible collateral and potential stigma effects.

in LCR. The problem of the bank is the following:

$$\max_{q,b_0,b_s} \mathbb{E}\left[\left((1-q)\,R_2 + (q-f_s)R_1 - (1-f_s)r - (b_0+b_s)\lambda c\right)\mathbb{1}_{[q+b_s\lambda\geq f_s]}\right] \quad \text{subject to } q+b_0\lambda \geq \rho, \tag{4}$$

where $q + b_0\lambda \geq \rho$ is the liquidity requirement imposed by liquidity regulation. One can see that the bank has two ways to finance the liquidity buffer. It can directly hold liquid assets, q, or pledge b_0 units of illiquid assets to borrow $b_0\lambda$ units from public liquidity backstops. Note that an implicit assumption here is that borrowing from public liquidity backstops does not further increase the required liquidity buffer. This is true in practice because regulators often assume that public liquidity backstops are unlikely to run on banks, so the "run-off rate" is 0% for the short-term funding from the discount window and is 0%–25% for the FHLBs.

Regulators choose the liquidity requirement ρ and the cost of accessing public liquidity c to maximize the social welfare:

$$\max_{\rho,c} \mathbb{E}\left[(1-q)\,R_2 + (q-f_s)R_1 - (b_0+b_s)\lambda w - \mathbb{1}_{[q+b_s\lambda\geq f_s]}L\right], \tag{5}$$

where w is the social cost of supplying public liquidity. Given the social welfare function equation (5), we can derive the socially optimal allocation, (q, b_0, b_G, b_B):

Proposition 1. *The socially optimal allocation, (q, b_0, b_G, b_B), is the following:*

- *If the liquidity premium is higher than the expected social cost of public liquidity, $R_2 - R_1 > pw$, then the private holding of liquidity is zero and the bank uses public liquidity to meet early withdrawals in the bad state, $(q, b_0, b_G, b_B) = (0, 0, 0, \frac{\Delta}{\lambda})$.*
- *If the liquidity premium is lower than the expected social cost of public liquidity, $R_2 - R_1 < pw$, then the private holding of liquidity is Δ and the bank uses its own liquidity buffer to meet early withdrawals in the bad state, $(q, b_0, b_G, b_B) = (\Delta, 0, 0, 0)$.*

Proof: See Appendix.

Proposition 1 formalizes the argument of Stein (2013), which says a central premise justifying preventative liquidity regulation is that supplying public liquidity is socially costly, so it is an explicit policy objective to economize its use. In Section 6, we show

that a price-based mechanism used by Australia's central bank can implement the socially optimal outcome.

In contrast, liquidity regulation alone may not be able to achieve the socially optimal outcome. On the contrary, a tightening of liquidity regulations while public liquidity is underpriced may actually increase banks' reliance on public liquidity. Formally, we can derive the following result:

Proposition 2. *If the lending capacity of the public liquidity backstop is unlimited, there is a threshold cost of public liquidity, c_1, which is determined by the following equation:*

$$c_1 = \frac{\rho}{\rho + p\Delta} \left(R_2 - R_1\right), \tag{6}$$

and

$$\frac{\partial c_1}{\partial \rho} = \frac{p\Delta}{(\rho + p\Delta)^2} \left(R_2 - R_1\right) > 0, \tag{7}$$

such that

- *If the cost of public liquidity c is higher than c_1, at date 0 the bank holds $1 - \rho$ units of illiquid assets and pledges $b_0 = 0$ units to the public liquidity backstop; at date 1, the bank does not access the public liquidity backstop: $b_G = b_B = 0$.*
- *If the cost of public liquidity c is lower than c_1, at date 0 the bank holds 1 unit of illiquid assets and pledges $b_0 = \frac{\rho}{\lambda}$ units of illiquid assets to the public liquidity backstop; at date 1, the bank pledges $b_B = \frac{\Delta}{\lambda}$ units of illiquid assets to public liquidity backstop.*

Proof: See Appendix.

In the socially optimal allocation, the bank never accesses the public liquidity backstop at date 0 because there is no withdrawal at this date. However, when public liquidity is underpriced ($c < c_1$), this is not the case anymore: the bank borrows public liquidity to meet liquidity regulation at date 0. Such transaction constitutes a regulatory arbitrage because it serves no economic purpose. Instead, it increases the use of public liquidity, which is inconsistent with the goal of liquidity regulation. Furthermore, when public liquidity is underpriced, a tightening of liquidity regulations does not reduce the quantity of illiquid assets ($\frac{\partial(1-q)}{\partial \rho} = 0$) because the low-cost public liquidity allows the bank to

transform its illiquid assets into liquid assets. As a result, illiquid assets are able to stay on the bank's balance sheet and the amount of liquidity transformation remains unchanged.

To prevent such regulatory arbitrage, the regulator needs to set the cost of public liquidity in conjunction with liquidity regulation. As shown in Proposition 2, a tightening of the liquidity requirement ρ must be accompanied with an increase in the cost of public liquidity, $\frac{\partial c_1}{\partial \rho} > 0$. Otherwise, the bank will borrow public liquidity to meet the liquidity requirement, defeating the purpose of liquidity regulation.

So far, we have assumed that the lending capacity of the public liquidity backstop is unlimited. In practice, the lending capacity may be binding in some states of the world. For instance, in the recent crisis, the lending capacity of FHLBs significantly shrunk after two other housing GSEs, Fannie Mae and Freddie Mac, ran into trouble, which led investors to question the health of FHLBs (Ashcraft, Bech, and Frame 2010). We incorporate this possibility by assuming that in the bad state of the world, the lending capacity of the public liquidity backstop shrinks to $\phi < \Delta$. Facing a public liquidity backstop with unstable lending capacity, the problem of the bank becomes the following:

$$\begin{aligned} \max_{q,b_0,b_s} \mathbb{E}\left[\left((1-q)\,R_2 + (q + b_s\lambda - f_s)R_1 - (1-f_s)r - (b_0 + b_s)\,\lambda c\right)\mathbb{1}_{[q+b_s\lambda \geq f_s]}\right] \\ \text{subject to } q + b_0\lambda \geq \rho \\ b_B\lambda < \phi. \end{aligned} \tag{8}$$

In this case, we find that bank runs can still occur even if the bank meets the liquidity regulation. Formally, we can prove the following result:

Proposition 3. *If the bank faces a public liquidity backstop with unstable lending capacity that shrinks to $\phi < \Delta$ in the bad state, there is a threshold cost of public liquidity, c_2, which is determined by the following equation:*

$$c_2 = \frac{1}{(1-p)\rho}(\rho\,(R_2 - R_1) + p(-R_2 + r + \Delta(R_1 - r_1))), \tag{9}$$

and

$$\frac{\partial c_2}{\partial \rho} = \frac{p(R_2 - r - (R_1 - r)\Delta)}{(1-p)\rho^2} > 0, \tag{10}$$

such that

- *If the cost of public liquidity c is higher than c_2, at date 0 the bank holds $1-\rho$ units of illiquid assets and pledges $b_0 = 0$ units to the public liquidity backstop; at date 1, the bank does not access the public liquidity backstop, $b_G = b_B = 0$. The bank is solvent in both states.*

- *If the cost of public liquidity c is lower than c_2, at date 0 the bank holds 1 unit of illiquid assets and pledges $b_0 = \frac{\rho}{\lambda}$ units of illiquid assets to the public liquidity backstop; at date 1 the bank defaults in the bad state.*

Proof: See Appendix.

It may be surprising that bank runs may still occur even if the bank meets the liquidity regulations. The key issue here is that the liquidity buffer is essentially borrowed from the public liquidity backstop on a short-term basis. In the bad state, as the lending capacity of the public liquidity backstop shrinks, the bank cannot roll over all of its loans and has to return part of the borrowed liquidity to the public liquidity backstop. This leaves insufficient liquidity to meet the withdrawals of depositors. This result shows that borrowing liquidity on a short-term basis does not effectively deter bank runs. Instead, it creates a phantom liquidity problem: liquidity appears to be abundant in normal times but can quickly disappear in bad times.[14]

Another issue of collateral transformation is that such transactions encumber the balance sheet of the bank, which increases the potential losses of other creditors in the event of bank failure. Formally, when public liquidity is underpriced, the bank pledges $\frac{\rho}{\lambda}$ units of illiquid assets as collateral to the public liquidity backstop. In the event of bank failure, unsecured creditors will suffer a greater loss because only $1-\frac{\rho}{\lambda}$ units of illiquid assets can be recovered. This may make them more likely to run. In practice, some deposits are insured by the FDIC. As a result, if more assets are encumbered, the exposure of the FDIC to bank failure becomes higher.

5 Empirical Evidence

In this section, we first describe the data. Then, we evaluate our model predictions empirically.

[14] If the liquidity is borrowed on a long-term basis, then the FHLBs will not have enough liquidity to repay their creditors at date 1.

5.1 Data

We combine several data sources to analyze the linkages between commercial banks, FHLBs, and MMFs. The summary statistics are reported in Table 1. We first use the Call Reports for balance sheet information of U.S. commercial banks. We consider the sample period from 2011 to 2014, the four-year window surrounding the fourth quarter of 2012 during which the Fed carried out its first ever system-wide stress test of bank liquidity. We follow the methodology of Hong, Huang, and Wu (2014) to calculate the liquidity coverage ratio for banks. The average LCR is 1.08 but there is considerable heterogeneity across banks. On average, 2.5% of the balance sheets is financed by FHLB advances, which accounts for 38% of banks' wholesale funding.

Second, we use iMoneyNet for information about U.S. MMFs. This data set provides fund-level information on asset size, yields, and fund families. Since a regulatory reform by the SEC in 2010, MMFs in the United States are required to file their detailed portfolio information at the individual security level with the SEC through N-MFP forms. We take advantage of this newly available information to trace the shift in portfolio composition of U.S. MMFs in response to the post-crisis liquidity regulations. Our sample on MMFs is from July 2011 to December 2017 with monthly frequency. We collapse the observations to fund-family level. In our sample, the share of the loans made to the FHLBs is around 12% of the total assets of a fund family.

Finally, we manually compile a unique data set on the balance sheets of the FHLBs and the pricing of FHLB advances and debt. We collect the balance sheets and income statements from SEC filings from 2011 to 2017 with quarterly frequency. Advances account for 56.9% of the total assets of the FHLBs. The FHLBs are highly levered. The average capital ratio is 5.2%, which is only half of the average capital ratio of banks. We complement the balance sheet data of the FHLBs with the issuance and pricing data collected from the websites of FHLB Boston, FHLB Dallas, FHLB Des Moines, the FHLB Office of Finance, and the Mergent Fixed Income Securities Database (FISD). Lastly, we obtain benchmark yields of money market instruments from the FRED database of the Federal Reserve Bank of St. Louis.

5.2 Liquid Buffer Held by Banks

We first examine the effect of post-crisis liquidity regulations on the holding of HQLAs by commercial banks. Panel A of Figure 2 plots the amount of HQLAs as a fraction of the total assets of U.S. commercial banks from 2011 to 2014. The solid line represents the "LCR banks," which are banks with total assets above $250 billion or on-balance sheet foreign exposure above $10 billion as of November 2012.[15] The dashed line represents non-LCR banks.[16] The vertical line indicates November 2012, the month when the Fed carried out its first ever system-wide stress test of bank liquidity. We choose it as the starting date of post-crisis liquidity regulations. We normalize the starting level of HQLAs to 0. We find that the holdings of HQLAs were similar across the two groups of banks. Following the introduction of liquidity regulations in late 2012, LCR banks substantially increased their HQLAs compared to the non-LCR banks.

We confirm the observation from the graph using a difference-in-differences regression model. We define *Post* as a dummy variable that equals 1 if the time is after 2012 Q4.[17] Our sample is the four-year window surrounding the treatment event in 2012 Q4. We define *LCR Bank* as a dummy variable that equals 1 if a bank was subject the full LCR in 2012 Q4. The coefficient of the interaction term between *LCR Bank* and *Post* captures the effect of liquidity regulation. The regression model is

$$HQLA_{i,t} = \beta Post_t * LCR\ Bank_i + \gamma X_{i,t} + \tau_t + \tau_i + \epsilon_{i,t}, \tag{11}$$

where $X_{i,t}$ is a set of control variables including the lagged log assets, deposit ratio, and capital ratio. The estimation results are presented in Table 2. We include bank fixed effects and time fixed effects consecutively to absorb unobservable differences in bank business models and macro-economic shocks such as quantitative easing. We find that LCR banks increase their HQLA holdings by around 3.6% of the total assets in the post-regulation

[15] Eight banks satisfy the criteria. In this graph, we exclude Capital One because its HQLAs appear to vary dramatically from quarter to quarter. However, including this bank would not change the main regression results.

[16] Note that banks with between $50 billion and $250 billion in assets are subject to a modified LCR, which is more lenient than the full LCR. In the Online Appendix, we find that the modified LCR does not seem to be binding in our sample period. Therefore, we classify all banks with assets below $250 billion as non-LCR banks. The result is robust to alternative classification schemes.

[17] The result is robust to other alternative cutoff dates because the effect of liquidity regulation is quite persistent. The result using alternative cutoffs can be found in the Online Appendix.

period compared to the control group. The magnitude is robust to the inclusion of bank and time fixed effects.

One may worry that some macro-economic shocks in the post period may affect the two groups of banks differently, which may drive our result. To sharpen our identification, we examine the cross-sectional relation between the pre-regulation liquidity coverage ratio and the subsequent changes in the HQLA holdings among the eight LCR banks in Panel A of Figure 4. We find that banks were further from meeting the new requirements tend to increase HQLAs by a larger amount subsequently. This result suggests that the increase in the HQLAs is indeed driven by liquidity regulation.

5.3 Collateral Transformation

At a first glance, the increase in banks' holdings of HQLAs seems to suggest that liquidity regulation has achieved its goals. However, a closer look at the lending relationship between banks, the FHLBs, and MMFs reveals a worrying trend: a significant fraction of the liquidity buffer is created through collateral transformation provided by the FHLBs.

The collateral transformation process is illustrated in Figure 1. Banks pledge their illiquid assets to the FHLBs to borrow liquid assets, then the FHLBs borrow from MMFs to lend to banks. The unique advantage of the FHLBs to intermediate this trade is their status as government-sponsored enterprises. This status allows the FHLBs to raise funding at a lower cost than private institutions. It also gives them access to a large pool of investors who exclusively invest in government securities such as government MMFs. Furthermore, as a public liquidity backstop, the FHLBs are treated by the LCR as a stable funding source for banks. Therefore, borrowing from the FHLBs has much smaller impact on the required liquidity buffer than borrowing from private institutions.[18]

We first examine the cost for banks to conduct collateral transformation with the FHLBs. The collateralized loans from the FHLBs to banks are commonly known as "FHLB advances." Unlike the discount window, borrowing from the FHLBs has little stigma (Ashcraft, Bech, and Frame, 2010). The FHLBs also offer more favorable rates. Figure 3 plots the 3-month FHLB advance rate,[19] the discount rate from the Fed's dis-

[18]For instance, the run-off rate of 30-day FHLB advances with non-HQLAs as collateral is 25%, while the run-off rate of secured borrowing with similar terms from a private counterparty is 100%.

[19]Banks need to put down 4%–5% of principal borrowed as activity-based capital, which will be returned when the associated advances have been repaid. In the meantime, banks receive high dividends from the

count window,[20] and the 3-month asset-back commercial paper (ABCP) rate.[21] We find that unlike the discount window, which charges a penalty rate, the FHLB advance rates are competitive compared to private market rates. Although the roll-out of liquidity regulations since late 2012 might have increased the demand for access to public liquidity, the FHLB advance rates remained largely unchanged. This could make the FHLBs an attractive source for obtaining liquidity to meet liquidity requirements.

We test this hypothesis by examining banks' borrowing from the FHLBs. Panel B of Figure 2 plots the amount of advances from the FHLBs to commercial banks from 2011 to 2014. The solid line and the dashed line represent the LCR banks and the non-LCR banks respectively. We normalize the starting level of advances to 0. We find that LCR banks have significantly increased their advances compared to non-LCR banks since the introduction of liquidity regulations. To confirm the graphical observation, we again employ the difference-in-differences strategy by comparing LCR banks to non-LCR banks. The regression model is similar to equation (11):

$$Advances_{i,t} = \beta Post_t * LCR\ Bank_i + \gamma X_{i,t} + \tau_t + \tau_i + \epsilon_{i,t}, \tag{12}$$

where *Advances* is the amount of advances normalized by total assets. Other variables are constructed in the same way as in equation (11). Table 3 presents the results. We find that LCR banks increased their advances by around 1.3% of the total assets during the two-year period after the introduction of liquidity regulations compared to the control group. Comparing the coefficients with Table 2, the increase in advances accounts for around 30% of the increase in the HQLAs in this period.

Panel B of Figure 4 further relates the pre-regulation liquidity coverage ratio of each of 8 LCR banks to the subsequent changes in advances. We again find a strong negative relationship: banks which have low liquidity coverage ratio increase their borrowing by more. This evidence further lends support to the hypothesis that the increase in advances is driven by the liquidity regulation.

activity-based capital. We adjust the FHLB advance rates by these dividends, which lowers the effective borrowing costs by around 12 basis points.

[20] Note that the discount rate is an overnight rate.

[21] Because FHLB advances are collateralized loans, we use asset-backed commercial paper (ABCP) as a benchmark. The result is quite similar with other maturities or other money market instruments such as financial commercial paper and repos. It should, however, be noted that the depth of the ABCP market is limited, and the eligible collateral in ABCP markets and repo markets may be more restricted than the ones eligible for FHLB advances. The haircuts may also vary.

What do banks do with the liquidity borrowed from the FHLBs? According to the mission of the FHLBs, advances should be used to promote housing finance and community investment. In this case, we should expect an increase in real estate loans made by banks when they draw more advances. In contrast, if advances are used to meet liquidity regulation, we should expect an increase in the HQLAs. To examine the usage of advances, we construct binned scatter plots of the annual changes in advances against the contemporaneous changes in real estate loans or HQLA. The result is shown in the top panel of Figure 5. All the quantities are expressed as a percentage of bank assets. The sample period is from 2012Q3 to 2014Q4. We find a striking difference in the behavior between LCR banks and non-LCR banks. For non-LCR banks, an increase in the advances is associated with a contemporaneous increase in real estate loans. However, for LCR banks, an increase in the advances is associated with a contemporaneous increase in HQLA.

5.4 Effect of Money Market Reform on the Funding of FHLBs

So far we have shown that the liquidity regulations on banks increase the *demand* for liquidity from the FHLBs. In this section, we show that the other major component of the post-crisis liquidity regulations, the 2016 money market reform, reinforced this trend by increasing the *supply* of liquidity to the FHLBs.

The money market reform restricts liquidity rights that prime MMFs, whose assets were primarily private debt, can provide to their investors. However, government MMFs are exempted from some of the most stringent rules such as the floating NAV requirement. This has resulted in a massive shift of deposits out of prime MMFs into government MMFs. Figure 6 plots the aggregate assets held by MMFs by fund types. The light area represents government funds, which can only hold treasury or agency debt. The dark area represents prime funds, which can also hold riskier private debt, such as bank commercial paper. The first red vertical line indicates the date when money market reform was finalized, July 2014. The second red vertical line indicates the implementation deadline of October 2016. We can see that almost $1 trillion deposits shifted from prime funds to government funds leading up to the implementation deadline.[22]

As more assets shifted from riskier prime funds to safer government funds, it seems that the MMF industry became safer overall. However, an analysis of the security-level

[22]The shift of deposits from prime funds to government funds is also documented in Cipriani, La Spada, and Mulder (2017) and Narajabad and Gissler (2018).

data on MMF holdings shows a more nuanced view. We find that the MMF industry has substantially increased their lending to FHLBs. Figure 7 shows that the aggregate holding of FHLB debt by MMFs has increased from 5% of their total assets before the reform to a striking 20% after the reform. The total dollar amount skyrocketed to $500 billion and accounted for half of the liabilities of the FHLBs at the end of 2017. The MMF industry has essentially become the single largest creditor of the FHLBs.

To investigate the reason behind the striking increase in lending to FHLBs by MMFs, we further break down the holding of FHLB debt into two groups of fund families according to their exposure to money market reform. As discussed above, prime funds are more affected by money market reform. Therefore, fund families that have more assets under prime funds should be more affected by money market reform. Following this logic, we separate all the fund families into two groups based on whether more than 50% of their assets were in prime funds as of January 2014. The dark blue area in Figure 7 shows the contribution of FHLB lending from the more-exposed fund families, while the light blue area shows the contribution of the less-exposed fund families. Figure 7 reveals an interesting pattern. Before money market reform, these two groups of fund families had similar FHLB debt holdings. However, leading to the reform deadline, the fund families that had higher exposure to the reform substantially increased their FHLB debt holdings. In fact, most of the increase in the FHLB debt can be attributed to these more-exposed fund families.

This observation is confirmed in a regression analysis. We examine the 6-year window around July 2014, the month when the final MMF rule was released. The unit of observation is the fund-family-quarter combination. We measure the fraction of FHLB debt held by each fund family and relate it to its exposure to money market reform as measured by the fraction of assets in prime funds pre-reform. The regression model is:

$$FHLB\ Debt_{i,t} = \beta Post_t * Exposure_i + \gamma X_{i,t} + \tau_t + \tau_i + \epsilon_{i,t}, \tag{13}$$

where *Post* is a dummy variable that equals 1 if the month is equal to or after July 2014, the month when money market reform was finalized, and zero otherwise.[23] *Exposure* is defined as the fraction of prime fund assets in the fund family. We also include fund family characteristics and time and fund fixed effects to absorb unobservable macro economic

[23]We choose this date rather than the implementation deadline of October 2016 to account for the anticipation of MMFs. The result is robust to use the alternative cutoff.

shocks and time-invariant fund family characteristics. Table 4 shows that consistent with Figure 7, higher exposure to money market reform leads to more FHLB debt.

The increase in the funding supply from MMFs to the FHLBs further lowers the cost for banks to transform collateral with the FHLBs. As shown in Figure 3, the FHLB advance rates are usually close to private market rates. However, before the deadline of money market reform in October 2016, the FHLB advance rates started to fall relative to the private market rates, reflecting the shift of funding from prime MMFs to government MMFs. This makes the FHLBs even more attractive for banks to obtain liquidity.

5.5 Summary of Empirical Findings

To summarize, the two major liquidity regulations, LCR and money market reform, affected the U.S. banking system in two phases. In the first phase (2012–2014), LCR increased the *demand* for FHLB advances by LCR banks. In the second phase (2015–2016), money market reform increased the funding supply of MMFs to the FHLBs, and consequently, the *supply* of FHLB advances to all banks. Taken together, these two liquidity regulations have significantly expanded the balance sheets of the FHLBs. The total assets of FHLBs increased by 50% during the period from 2012 to 2017 and reached $1.1 trillion by the end of 2017. At the same time, the FHLBs are increasingly funded by short-term debt. As of 2017, 70% of the FHLB balance sheets are financed by short-term debt.

5.6 Implications of Empirical Findings

This section discusses the policy implications of our findings. We first evaluate whether collateral transformation has compromised the goal of liquidity regulation. Then we evaluate whether facilitating collateral transformation is consistent with the housing mission of the FHLBs. Finally, we examine whether the FHLBs' lending concentration has increased following liquidity regulation.

5.6.1 Implications for Liquidity Regulation

Stein (2013) argues that an important goal of liquidity regulation is to reduce private banks' reliance on public liquidity backstops. However, our results suggest that the proliferation of

collateral transformation seems to paradoxically increase banks' reliance on public liquidity through the FHLBs.

A more concerning issue is that the collateral transformation is predominantly conducted on a short-term rolling basis. Table 5 shows that the maturity of collateralized loans between LCR banks and FHLBs appear to be exclusively less than one year. Furthermore, Figure 8 shows that the average maturity of loans between FHLBs and MMFs is below 40 days as of 2017.

Using short-term debt to finance liquidity buffers may create a phantom liquidity problem as shown in Proposition 3: liquidity appears to be abundant in normal times but may quickly disappear in stress times. Consider the following hypothetical scenario: if there is unexpected shock that triggers short-term creditors to withdraw their funding to MMFs, MMFs will be forced to withdraw funding from the FHLBs. The FHLBs in turn will be forced to withdraw the liquidity lent to banks. Banks will have significantly less liquidity to meet the withdrawals of creditors.

There are historical episodes that resemble the scenario described above. Ashcraft, Bech, and Frame (2010) document that in the first half of 2017, the FHLBs provided substantial amount of emergency funding to troubled banks acting as a "lender of next-to-last resort." However, following heightened concerns about the financial health of Fannie Mae and Freddie Mac during the summer of 2008, the FHLBs found themselves "guilty by association" and saw their borrowing costs rise, which forced them to shrink their lending to banks.

Were similar events to happen, the unraveling could be more severe because now the FHLBs rely on short-term debt more heavily than in the previous episode. Such unraveling may affect a significant fraction of liquidity buffers. Based our estimation, around 30 cent of each dollar of the liquidity buffers is created through the "collateral transformation".[24] This implies that a third of newly increased liquidity buffers may not be resilient in times of stress.

Finally, the collateral transformation encumbers banks' balance sheets and reduces the recovery rate for unsecured creditors in the event of bank failure. Therefore, unsecured

[24]We calculate the 30% by comparing the average increase in HQLAs and the average increase in advances for LCR banks in Table 2 and Table 3. Examining the aggregate quantity leads to a similar conclusion: from 2012 to 2017, the liquidity buffer of all U.S. banks increased by around $1,170 billion while banks' borrowing from the FHLBs and the FHLBs' borrowing from MMFs increased by $250 and $330 billion respectively.

creditors may become more prone to run in a stress scenario, which compromises the effectiveness of liquidity regulation to deter bank runs. The collateral transformation also creates externalities for the FDIC because the FHLBs have a "super lien" status. If a bank fails, the FDIC must repay the FHLBs before paying depositors. This increases the exposure of the FDIC to bank failures.

5.6.2 Implications for the FHLBs' Housing Mission

One may argue that a large FHLB balance sheet is not necessarily a bad thing because it is the government's intention to promote housing investment. Nevertheless, in light of our finding that the FHLB advances are used by large banks to meet the LCR requirements, it is unclear how much of the subsidy is passed through to the ultimate borrowers in the housing market. In this section, we estimate the total value of government subsidies to the FHLBs and the fraction that is passed through to the ultimate borrowers.

We start by computing the funding advantage of the FHLBs over private banks for different types of debts as shown in Figure 9. From 2011 to 2017, the FHLBs enjoyed a funding advantage of around 20–50 basis points compared to private financial institutions. The funding advantage was usually greater in periods of market stress. We then multiply the funding advantage with the corresponding dollar amount of outstanding debt, and sum across different types of debt to calculate the total subsidy. We find that the FHLBs received a substantial implicit subsidy: the average subsidy was \$3.2 billion per year from 2011 to 2017.

Next, we estimate the fraction of the subsidy passed through to the ultimate borrowers in the housing market using a simple supply and demand framework shown in Figure 11. D is the demand for real estate loans. S_0 is the supply of real estate loans if there are no FHLB advances. The advances increase the loan supply, which shift the supply curve to S_1. The shaded regions show the borrower surplus gain due to the advances, which can be calculated using the following equation:

$$\text{Subsidy to Borrowers} = (r_0 - r_1)q_0 + \frac{1}{2}(r_0 - r_1)(q_1 - q_0). \tag{14}$$

The first term is the blue area and the second term is the red area. The intuition of this formula is the following. If the government subsidy is passed through to the ultimate borrowers, we should see that more advances are translated into lower real estate loan

rates ($r_0 > r_1$) or greater quantity of real estate loans ($q_0 < q_1$). We can estimate the rate pass-through and the quantity pass-through using the following the regression model with a panel data of bank loan rates and loan quantities:[25]

$$q_{i,t} = \beta_1 a_{i,t} + \tau_t + \tau_i + \epsilon_{i,t} \tag{15}$$

$$r_{i,t} = \beta_2 a_{i,t} + \tau_t + \tau_i + \epsilon_{i,t}, \tag{16}$$

where $r_{i,t}$ ($q_{i,t}$) is the real estate loan rate (quantity) of bank i in quarter t. $a_{i,t}$ is the amount of FHLB advances.[26] We include time fixed effects to absorb the common time trends and bank fixed effects to absorb macro-economic shocks and unobservable bank characteristics. The estimated coefficient, β_1, can be interpreted as the increase in the real estate loan quantity per unit increase in advances, and $-\beta_2$ can be interpreted as the reduction in the real estate loan rates per unit increase in advances. Figure 10 plots the coefficient estimates and standard errors for each year. The black dashed line shows the quantity pass-through, β_1. We can see that a one dollar increase in the advances is translated into a 15-cent increase in real estate loans in 2011. However, the quantity pass-through declines substantially to around 5 cents following the roll-out of liquidity regulations. The rate pass-through, $-\beta_2$, shows a similar trend. A 1% increase in advances over assets decreases the real estate loan rates by 1.5 basis points in 2011, but it declines to 1 basis point in 2017. The decline in both the quantity and rate pass-through is consistent with our previous finding that banks start to use advances to purchase liquid assets rather than lend to the real estate market following the roll-out of liquidity regulations.

Given the estimates of quantity and rate pass-throughs, we can calculate the total changes in the real estate loan amount due to advances for bank i at quarter t as $q_1 - q_0 = \beta_1 a_{i,t}$, and the total changes in the real estate loan rate due to advances for bank i at quarter t as $r_1 - r_0 = \beta_2 a_{i,t}$. Finally, we can plug $r_1 - r_0$ and $q_1 - q_0$ into equation (14), to calculate the total subsidy bank i passes through to borrowers at time t. Our estimates show that on average, the FHLBs enjoy a \$2.74 billion subsidy each year due to the implicit government guarantee from 2013 to 2017. However, only 52% of the subsidy is passed through to

[25] Previous studies on the subsidy pass-through of Fannie Mae and Freddie Mac exploit the rate difference between conforming (subsidized) and non-conforming (unsubsidized) mortgages (CBO testimony 2011, Passmore 2005). This methodology does not work for FHLBs because there is no specific loan-size threshold for the FHLB advance to apply.

[26] Real estate loans and advances are normalized by banks' total assets.

borrowers in the housing market. This appears to be at odds with the main mission of the FHLB system, which is to promote housing and community investment.

5.6.3 Implications for Lending Concentration of the FHLBs

During the 2007-09 financial crisis, some FHLBs provided concentrated funding to banks engaging in unsound business practices (Gaberlavage, 2017). The Seattle FHLB was forced to merge with the Des Moines FHLB, in part due to the failure of its largest member, Washington Mutual. The concentrated lending during the crisis attracted a lot of criticism and led to regulatory efforts to reduce the lending concentration and shift the lending to small- and medium-sized financial institutions.[27] However, as the liquidity regulations increase the demand for advances among the biggest banks, the lending of FHLBs may have become more concentrated in the largest banks, which bear the brunt of liquidity regulation.

We systematically examine the lending concentration of the FHLB system. Figure 12 plots the average Herfindahl-Hirschman Index (HHI) of the advance lending for the FHLB system over time.[28] We can see that since the roll-out of liquidity regulation in late 2012, lending concentration has risen rapidly, from 12% to 18%. To show that liquidity regulation is indeed driving the increase in concentration, we construct a counterfactual HHI assuming that LCR banks' advance-to-asset ratio stays constant after 2012Q4. We find the counterfactual HHI stays almost flat, suggesting the rise in concentration is indeed driven by LCR banks. This result is consistent with anecdotal evidence that some of the largest banks dominate in some FHLBs' lending portfolios, an issue which raised concern among market participants.[29] Such development is inconsistent with the regulatory effort to reduce the FHLBs' lending concentration.

[27] See "Reforming America's Housing Finance Market: A Report to Congress," by the Department of the Treasury and the Department of Housing Development and Urban Development.

[28] We match regional FHLBs to commercial banks based on the location of the headquarters of commercial banks.

[29] For instance, an article in American Banker on April 28, 2017, reported that Wells Fargo's borrowings accounted for nearly 59% of Des Moines FHLB's total advances at the end of 2017.

5.7 Regulatory Fragmentation

The above discussion provides systematic evidence that post-crisis liquidity regulations have led to many unintended consequences that end up compromising the effectiveness of these regulations. In this section, we examine the institutional reasons that allow these unintended consequences to arise.

We suggest that regulatory fragmentation plays an important role. In the United States, different financial institutions are often regulated by different regulatory agencies: commercial banks are primarily regulated by the Federal Deposit Insurance Corporation (FDIC), the Federal Reserve Board, or the Office of the Comptroller of the Currency (OCC), MMFs are regulated by the SEC, while the FHLBs are regulated by the Federal Housing Finance Agency (FHFA).

These regulators usually have different and sometimes conflicting objectives. In our context, the objective of the bank regulators (the Fed, the FDIC, the OCC) is to use liquidity regulation to reduce banks' reliance on public liquidity backstops. The objective of the MMF regulator (the SEC) is to reduce liquidity risks of money market funds. The objective of the FHLB regulator FHLBs (the FHFA) is to promote housing and community investment. Because of this mandate, the FHFA seemed hesitant to limit the FHLBs' lending to banks when it noticed the rapid expansion of the advances. In a report, the Office of Inspector General of the FHFA notes the following:

"The benefits of the surge in advances to the four largest members include an increase in interest income that FHLBs earn from making advances. Further, FHFA defines all advances as 'core housing mission assets.' Thus, increased advances could address FHFA's concerns about the relatively high level of System investments in 'non-core housing mission assets,' such as mortgage-backed securities issued by Fannie Mae and Freddie Mac.

The risks include the significant losses an FHLB could incur if a large member defaults on its advances, particularly if the advances were improperly collateralized or the value of the collateral had declined significantly. FHFA officials emphasized that FHLB advances for the purpose of meeting recent liquidity requirements are legal and not inconsistent with the System's mission."[30]

[30] See Recent Trends in Federal Home Loan Bank Advances to JPMorgan Chase and Other Large Banks Evaluation, FHFA-OIG report, April 16, 2014.

As made clear by this quote, the FHFA believes that FHLBs' lending to banks is consistent with their mandate. However, from the perspective of the bank regulators, FHLBs' lending compromises the effectiveness of liquidity regulations. This case illustrates the lack of coordination among different regulators in the fragmented regulatory structure. Each regulator focuses on its narrowly defined mandate without taking into account the repercussions to others. This leads to many unintended consequences as documented above. In the following section, we discuss potential policy remedies to address these unintended consequences.

6 Potential Policy Remedies

In this section, we consider potential policy remedies to the unindented consequences documented above. We emphasize both the theoretical effectiveness as well as the practical feasibility based on the institutional arrangements in the United States.

6.1 Leverage Constraint

We first consider a leverage constraint on the FHLB which would limit its lending to banks to a fixed multiple of its capital. However, a particular institutional feature of the FHLBs may render the leverage constraint ineffective. As discussed more detail in the Appendix, banks need to contribute "activity-based capital" when borrowing from the FHLBs. This activity-based capital automatically relaxes the leverage constraint. To see this point, define e as the initial capital of the FHLBs; μ as the amount of activity-based capital that banks need to contribute per dollar of credit they get from the FHLBs; b as the amount of illiquid assets banks pledge to the FHLBs; λ as the collateral value; κ as the maximum leverage ratio. The leverage constraint can be written as the following[31]

$$1 + b\lambda \leq \kappa(e + b\lambda\mu). \tag{17}$$

When the the activity-based capital per unit of borrowing, μ, is large enough, the extra equity the FHLB raises through one dollar of lending can mitigate the negative impact on

[31] Notice that in practice, when computing regulatory capital, the initial equity, e, receives a weight of 1.5 while the activity-based capital, $b\lambda\mu$, receives a weight of 1. Here we use the same weight but the result does not change when we apply different weights.

the capital ratio (for instance, μ approaches $\frac{1}{\kappa}$). As a result, the leverage constraint will never be binding. Therefore, we do not expect the leverage constraint to be an effective tool to control the balance sheets of the FHLBs.

6.2 Collateral constraint

Next, we consider the option of tightening the collateral requirement for the bank to borrow from the FHLBs. Specifically, if we increase the haircut of the FHLBs so that the collateral value of illiquid assets $(1-q)\lambda$ is lower than the liquidity requirement ρ, then the bank cannot borrow enough liquid assets from the FHLBs. The drawback of this policy is that it reduces available liquidity for banks in times of crisis. In addition, it needs to be enforced by the FHLB regulator who may not have the incentive to reduce the lending to banks.

6.3 Adjusting the Run-Off Rates of Advances

We then consider a policy proposal that adjusts the run-off rates of advances. In practice, FHLB advances receive favorable run-off rates in LCR because they are viewed as a stable source of funding for the banks. However, this may not be a good assumption any more given that the FHLBs themselves are increasingly financed by short-term unstable funding. Therefore, a potential remedy is to adjust the run-off rate on the FHLB advances to reflect the lack of stability of the funding source of the FHLBs. Specifically, if the regulator assigns a higher run-off rates ρ_b on the FHLB advances, it will discourage the bank from borrowing from the FHLBs, because an increase in liquidity borrowed from the FHLBs also increases the required liquidity buffer. Formally, consider the following a new liquidity requirement for the bank:

$$q + b\lambda \leq \rho + \rho_b b\lambda \tag{18}$$

where $\rho_b b\lambda$ is the increase in liquidity buffer due to the borrowing from the FHLBs. If ρ_b is high enough, such transaction will not be profitable. Note that a higher ρ_b is mathematically equivalent to a tighter collateral constraint (a smaller λ). But in practice, adjusting the run-off rates of advances is probably more advantageous because it can be implemented by the bank regulator alone. Therefore, it circumvents the coordination issue

among different regulators. The downside of this approach is that banks may incur a high cost to meet liquidity regulations when liquid assets are scarce, i.e., $R_2 - R_1 > pw$.

6.4 Price-Based Mechanism

Finally, we consider the a price-based mechanism such as the Committed Liquidity Facility (CLF) used in Australia suggested by Jeremy Stein in a 2013 speech at the Federal Reserve Bank of Richmond. In this case, banks pay a fee to the central bank for a loan commitment. The *unused* capacity of the loan commitment of the CLF can be counted as liquidity buffers to meet LCR and banks do not have to draw the loan commitment to purchase liquid assets. The regulator sets the commitment fee of the CLF to reflect the expected social cost of supplying public liquidity. Specifically, the optimal fee of accessing the CLF, k, in our model is

$$k = pw \tag{19}$$

where k is the commitment fee; p is probability of the bad state in which case the loan commitment is drawn by banks; and w is the social cost of supplying public liquidity. Note that the commitment fee k is different from c, the cost for the drawn credit, which should be set to 0 in this case.

There are two important differences between the CLF and the FHLBs. First, the cost of borrowing from FHLBs is subsidized, which distorts banks' incentives to use public liquidity. In contrast, under the CLF, banks bear the social cost of liquidity transformation. Second, the lending capacity of the FHLBs is limited and could be unstable in times of crisis. In contrast, the lending capacity of the CLF is unlimited and stable because it is backed by the central bank's ability to create money.

This price-based mechanism has many advantages over the current quantity-based mechanism in the United States. The quantity-based mechanism forces banks to hold a certain amount of liquid assets regardless of the costs of doing so. If the liquidity premium turns out to be quite high, the quantity-based mechanism may lead to a high compliance cost for banks. In contrast, this price-based mechanism allows banks to switch between public and private liquidity depending on whether HQLAs are scarce. If HQLAs are not scarce, the liquidity premium $R_2 - R_1$ will fall below the commitment fee k and banks will hold liquid assets to meet liquidity regulations. If HQLAs are scarce, the liquidity premium $R_2 - R_1$ will rise above the commitment fee k and banks will pay the commitment fee to

the CLF to meet liquidity regulations. By equalizing the social cost of public liquidity to the commitment fee, this price-based mechanism achieves the socially optimal allocation derived in Proposition 1. The advantage of this price-based mechanism is greater in economies in which the HQLAs are scarce or the liquidity premium fluctuates significantly over time.[32]

7 Conclusion

In this paper, we provide a timely evaluation of the effects of liquidity regulation on the U.S. banking system. On the surface, we find that these liquidity regulations seem to achieve their goals: commercial banks hold greater liquidity buffers while the risky segment of the MMF industry, the prime MMFs, has shrunk significantly. However, digging deeper, we find that the banking system increasingly relies on a public liquidity backstop, FHLBs, to meet liquidity requirements: banks use the FHLBs to transform collateral while MMFs shift their short-term lending to FHLBs. We show that much of the implicit subsidy associated with the implicit government guarantee on the FHLBs accrues to banks rather than to the intended recipients, the mortgage borrowers. The increasing role of a government-sponsored enterprise in the aggregate liquidity transformation is at odds with the goal of reducing banks' reliance on public liquidity backstops.

We develop a simple model building on Diamond and Kashyap (2016) to show that any liquidity regulation must also simultaneously address the way in which government-supplied liquidity is priced. If public liquidity is underpriced, the illiquidity will tend to remain in the banking system, thereby compromising the goals of liquidity reforms. We use the model to consider several regulatory remedies for the unintended consequences. We show that a price-based mechanism used in Australia may help to align the private and social cost of accessing public liquidity and achieve the socially optimal outcome.

[32]The liquidity premium may fluctuate due to changes of monetary policy (Nagel, 2016) and supply of government debts (Krishnamurthy and Vissing-Jorgensen, 2012).

Appendix I: FHLB Institutional Background

The Federal Home Loan Bank system was established in 1932 to provide liquidity to thrift institutions (Romer and Weingast 1991). Established as 12 (now 11) regional banks, the system has used its status as government-sponsored enterprise to assist its member financial institutions to finance housing and certain types of community development lending. Despite of its importance in the U.S. banking system, the FHLBs remain little known by the public.

The FHLBs first received public scrutiny during the saving and loan crisis in the 1980s. In this period, the FHLBs relied on thrifts for lending business but at the same time served as their regulator. Significant conflicts of interests arose in those relationships, which prompted Congress to abolish the old regulator of the FHLBs and thrifts and install new ones (McCool 2005; Day 2019). Congress also opened FHLB membership to commercial banks and credit unions.

Unique Equity Structure

A unique feature of FHLB membership is that the borrowing members are required to post eligible collateral *and* equity capital to borrow money from an FHLB.[33] Members are required to capitalize all advances, typically at 4% to 5% of principal borrowed, and FHLB repurchases capital stock once the associated advances have been repaid. This is referred to as the "activity-based equity capital." The "permanent capital" of the FHLB is composed of Class B equity capital that the members must contribute in order to retain membership, which must remain committed for at least five years (see the discussion below) before it can be redeemed. Redemptions, when they occur, are at par value.[34] This feature suggests two potentially important economic implications: First, the borrowing members may have skin in the game by virtue of their equity in the FHLB: their equity will potentially be wiped out if the FHLB takes excessive risks and fails. As an example,

[33]The eligible collateral include U.S. Treasury Securities, agency securities, agency MBS, private label RMBS, CMBS, and municipal bonds. Ineligible collateral types include: corporate bonds, private placements, and public equities.

[34]Redeeming permanent equity capital may be costly. The FHLB states: "Any member that withdraws its membership from an FHLB may not acquire shares of any FHLB for five years after the date on which its divestiture of capital stock is completed, unless the institution has canceled its notice of withdrawal prior to that date. This restriction does not apply if the member is transferring its membership from one FHLB to another FHLB on an uninterrupted basis."

in 2009, the FHFA (the regulator of the FHLB system) prohibited the Seattle FHLB from paying dividends or redeeming its equity as a way to conserve the FHLB's capital.[35] This incentive may be undercut by the possibility that the FHLB system is backed by explicit and implicit government guarantees, and members who post equity may expect to get bailed out. Second, the FHLB has the ability to expand or contract its balance sheet in relation to the demand for loans from its members. We will expand on both these themes below.

Three features of FHLB equity are worth emphasizing: First, ownership is restricted as FHLB stock can only be sold to a member institution. Second, the stock can only be redeemed at par value. Finally, the equity lacks a market because there is no real "market" for the stock other than the FHLBs or member institutions. Given the fact that the membership is small, equity holders are fairly concentrated and are mostly big insured depository institutions.[36] While at a first glance, co-operative structure of the FHLB may be seen as being less risky than firms with outside equity holders, keen observers have noted that the FHLB system is difficult to fully comprehend and analyze. See, Greenspan (2004), for example.

Each regional FHLB is permitted to issue one or two classes of capital stock, each with subclasses, to its members. Members can redeem Class A stock by giving six-months' written notice, and members can redeem Class B stock by giving five-years' written notice, subject to certain restrictions. Most regional FHLBs only issue Class B stock, with some offering sub-classes of Class B stock, which represent either membership or activity-based stock requirements based upon the terms of the respective regional FHLB's capital plan. Each regional FHLB has the ability to hold capital up to five years. Therefore, the FHLB is able to scale up or scale down capital, depending on the size of its balance sheet. This is referred to as a controlled scalability. The two subclass Class B stockholders may or may not have the same voting rights and dividend rates, which are based on the terms of the respective FHLB's capital plan.[37]

[35] See Merger of the Federal Home Loan Banks of Des Moines and Seattle: FHFA's Role and Approach for Overseeing the Continuing FHLB, white paper, FHFA, March 16, 2016.

[36] Flannery and Frame (2006) make the point that "the Banks' equity holders are the member financial institutions, while their bondholders are widely dispersed throughout the capital markets. These two groups remain distinct in the FHLB structure, rendering the 'bundling of claims' argument inapplicable. Hence, the cooperative structure of the FHLB System does not necessarily insulate the Banks from excessive risk taking."

[37] Source: Discussion of the FHLBs' Capital Structure and Regulatory Capital Requirements, Federal Home Loan Bank System, Office of Finance, August 23, 2018.

Stock ownership entitles the borrowing members to dividend payments on both classes of equity capital to which the member contributes. For example, FHLB-Boston reported that the dividend payout for its equity holders was 300 basis points above LIBOR.[38] The activity-based equity usually generates higher dividend payouts relative to the permanent (membership) equity. This type of payout is handsome, considering the low interest rates that prevailed during this period. It shows that while the equity holders redeem equity at par, there is nevertheless some upside potential through dividend payments. This feature is pertinent when calculating the net costs of obtaining cash advances from FHLB by the member banks. It is also relevant to thinking about how any government subsidy that may be backing the FHLB system is divided between FHLB regional banks and the member banks who borrow from the FHLBs.

The FHLB's Funding Advantages

The FHLB regional banks enjoy both explicit and implicit funding advantages. Gaberlavage (2017) notes that the FHLB Act confers on the FHLBs a number of special privileges and exemptions that result in lower costs, which include the following. First, the Treasury may purchase up to $4 billion of FHLB securities (line of credit for system as a whole): One might argue that this is small relative to the size of the balance sheet of the FHLB system, but the symbolic significance is important. Second, FHLB debt is eligible for Federal Reserve open market purchases, including unlimited investment by insured commercial banks and thrifts and collateralizing public deposits. Third, FHLBs enjoy exemption from the bankruptcy code because they are considered "federal instrumentalities." FHLBs have priority on collateral claims on member institutions, over any and all other creditors (the "super lien"). Fourth, FHLBs' earnings are exempt from federal, state, and local income tax. Fifth, Interest paid to investors is exempt from state income taxes. These features make the debt issued by FHLBs very attractive to institutional investors.

One of the key funding channels for the regional FHLBs is the Office of Finance. All senior, unsecured debt securities issued through the Office of Finance are the joint and several obligations of the entire FHLB system. This arrangement also implies that any major exposure faced by a single regional FHLB may spill over into the entire system. This observation is important as regional FHLBs have had big exposures to just a few big banks, causing some debate in policy circles.

[38] Federal Home Loan Bank Funding Strategies for Insurance Companies, FHLB Boston, 2Q2016.

FHFA Capital Requirements and Regulations

The FHFA imposes certain capital requirements on the regional FHLBs. FHLBs must maintain a minimum of 4% total capital ratio. This capital is defined as the sum of permanent capital (5-year Class B stock plus retained earnings) and amounts paid for Class A stock (6-month redeemable), plus any general loss allowance and other sources approved by the regulator. In addition, the FHFA requires a minimum leverage capital ratio of 5%. The capital applicable here is the sum of permanent capital weighted by a 1.5 multiplier, plus all other capital. Finally, there are also risk-based capital requirements, which can vary across regions. To preserve capital, FHLBs may voluntarily suspend or eliminate dividends and/or early excess stock repurchases, and may increase the membership and/or activity-based stock requirements. The FHFA can limit dividends and stock redemptions. It retains the ultimate authority to place any FHLB into conservatorship or to merge FHLBs (as discussed earlier with regarding the Seattle FHLB).

Appendix II: Proofs

Proof of Proposition 1

We can rewrite the regulator's problem in terms of quantities:

$$\max_{q,b_0,b_G,b_B} (1-q)\,R_2 + (q-p\Delta)R_1 - (b_0 + (1-p)b_G + pb_B)\lambda w - \mathbb{1}_{[q+b_B\lambda\geq\Delta]}L. \tag{20}$$

We can see that the socially optimal allocation must prevent bank runs but never waste either public or private liquidity:

$$q + b_B\lambda = \Delta. \tag{21}$$

The bank does not use public liquidity in normal times because there is no economic benefit to do so.

$$b_0 = b_G = 0 \tag{22}$$

Plug in the use of public liquidity, b_0, b_G, b_B, we have

$$\begin{aligned} \max_q (1-q)\,R_2 + (q-p\Delta)R_1 - (\Delta - q)pw \\ \text{subject to } 0 \leq q \leq \Delta. \end{aligned} \tag{23}$$

The first-order condition is

$$R_2 - R_1 = pw. \tag{24}$$

The left-hand-side is the social cost of private liquidity. The right-hand-side is the expected social cost of public liquidity. If $R_2 - R_1 > pw$, using public liquidity is socially optimal, $b_B\lambda = \Delta$. If $R_2 - R_1 < pw$, using private liquidity is socially optimal, $q = \Delta$.

Proof of Proposition 2

We compare two choices of the bank:

Choice 1: holds $1-\rho$ units of illiquid assets and pledges $b_0 = b_s = 0$ units to the public liquidity backstop. The expected profit is the following

$$(1-\rho)\,R_2 + (\rho - p\Delta)R_1 - (1-p\Delta)r. \tag{25}$$

Choice 2: holds 1 units of illiquid assets and pledges $b_0 = \rho$ units to the public liquidity backstop. The expected profit is the following

$$R_2 + (-p\Delta)R_1 - (1 - p\Delta)r - (\rho + p\Delta)c. \tag{26}$$

The indifference condition between the two choices gives the threshold.

$$c_1 = \frac{\rho}{\rho + p\Delta}\left(R_2 - R_1\right). \tag{27}$$

Proof of Proposition 3

We compare two choices of the bank:

Choice 1: holds $1-\rho$ units of illiquid assets and pledges $b_0 = b_s = 0$ units to the public liquidity backstop. The expected profit is the following

$$(1 - \rho)\, R_2 + (\rho - p\Delta)R_1 - (1 - p\Delta)r. \tag{28}$$

Choice 2: holds 1 units of illiquid assets and pledges $b_0 = \rho$ units to the public liquidity backstop at date 0 and defaults the bad state of date 1. The expected profit is the following

$$(1 - p)(R_2 - r - \rho c). \tag{29}$$

The indifference condition between the two choices gives the threshold.

$$c_2 = \frac{1}{(1-p)\rho}(\rho\,(R_2 - R_1) + p(-R_2 + r + \Delta(R_1 - r_1))). \tag{30}$$

$$\frac{\partial c_2}{\partial \rho} = \frac{p(R_2 - r - (R_1 - r)\Delta)}{(1-p)\rho^2} > 0. \tag{31}$$

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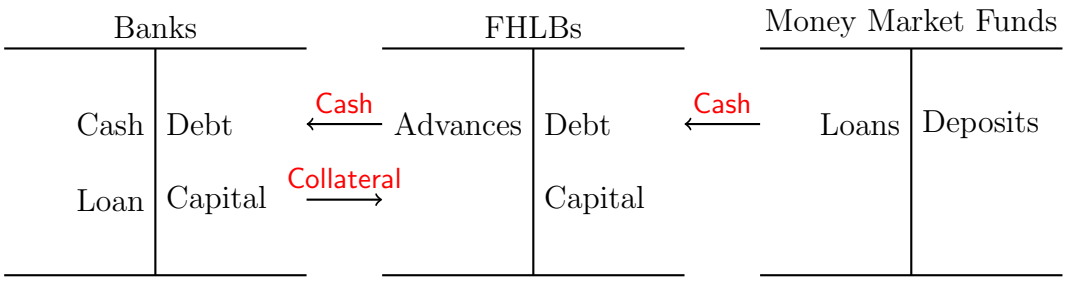

Figure 1: How U.S. Banking System Responds to Liquidity Regulations
This diagram illustrates the process of collateral transformation through the FHLBs. Banks first pledge illiquid assets to the FHLBs in exchange for liquid assets. Then the FHLBs borrow from MMFs to lend to banks.

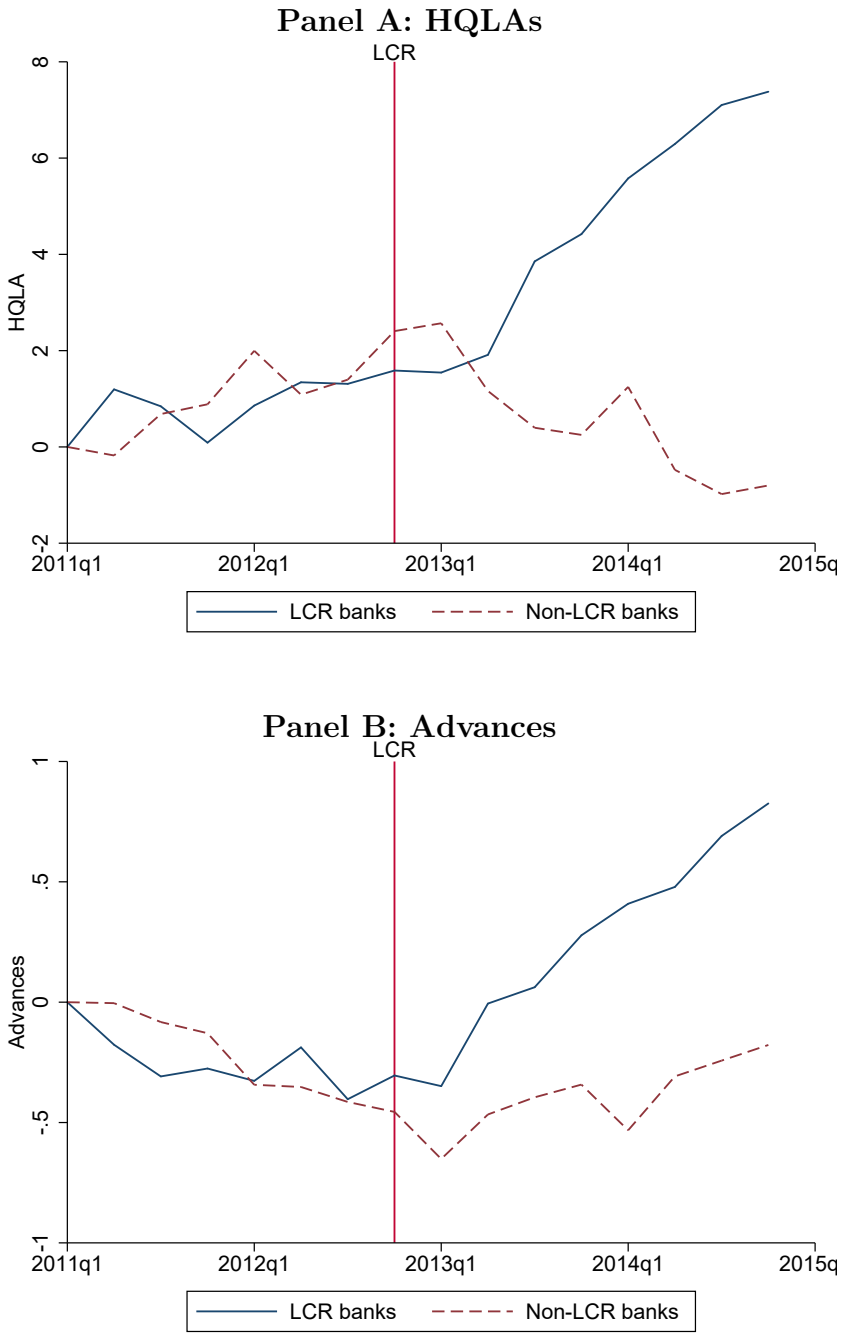

Figure 2: HQLAs and Advances of LCR Banks vs. Non-LCR Banks
This figure plots the high quality liquid assets (HQLAs) and FHLB advances of U.S. commercial banks over assets. The solid line shows LCR banks. The dashed line shows the non-LCR banks. Both lines are normalized to 0% at the beginning of the sample period. The sample period is from 2011 to 2014. Data source: Call Report.

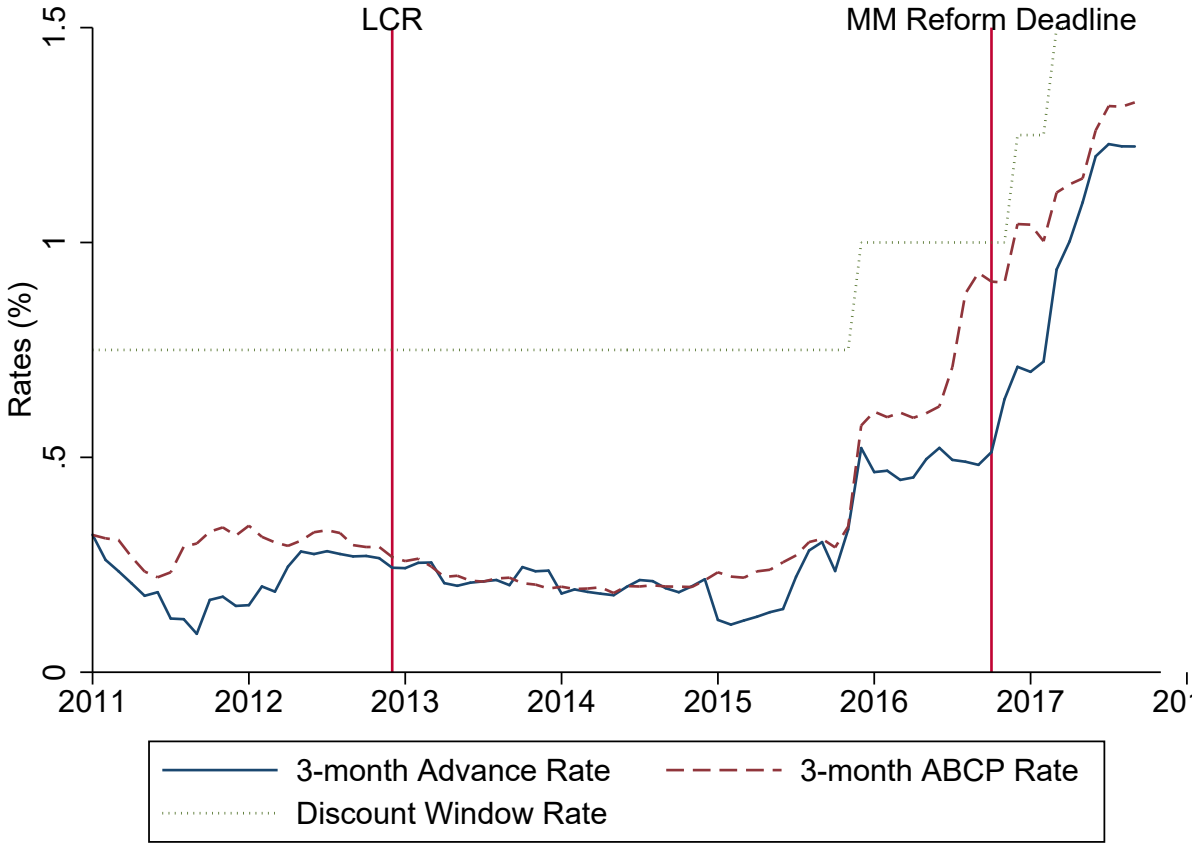

Figure 3: FHLB Advance Rates, ABCP Rates, and Discount Rate
This graph plots the 3-month FHLB advance rates, ABCP rates, and the discount rate from the discount window from 2011 to 2017. Data source: FHLB Boston, Dallas, and Des Moines; Federal Reserve Bank of St. Louis.

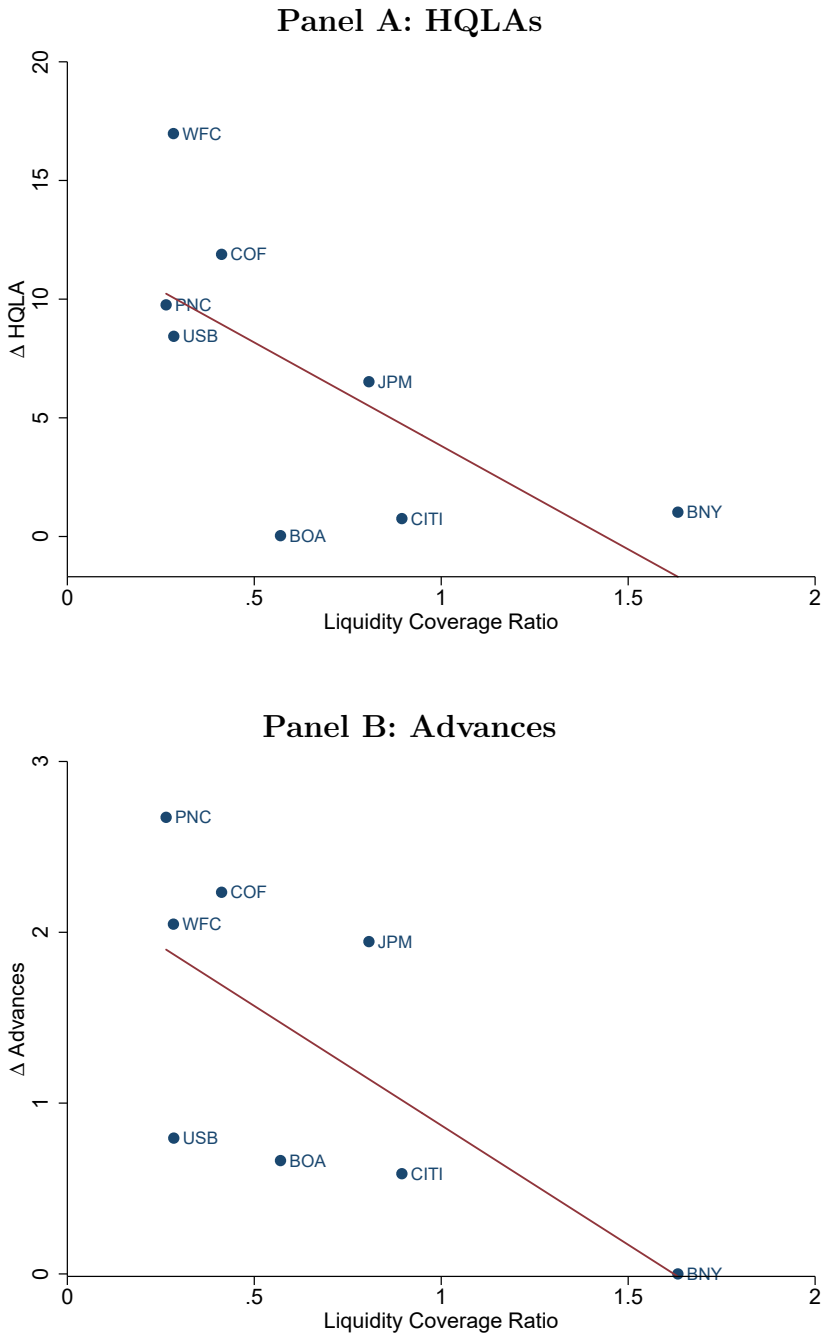

Figure 4: Pre-Regulation LCR and Changes in HQLAs and Advances
This figure shows cross-section relation between the liquidity coverage ratio before liquidity regulation (2012Q3) and the subsequent changes in HQLAs and the FHLB advances (2012Q3–2014Q4) for the eight LCR banks. Each dot represents a bank. Data source: Call Report.

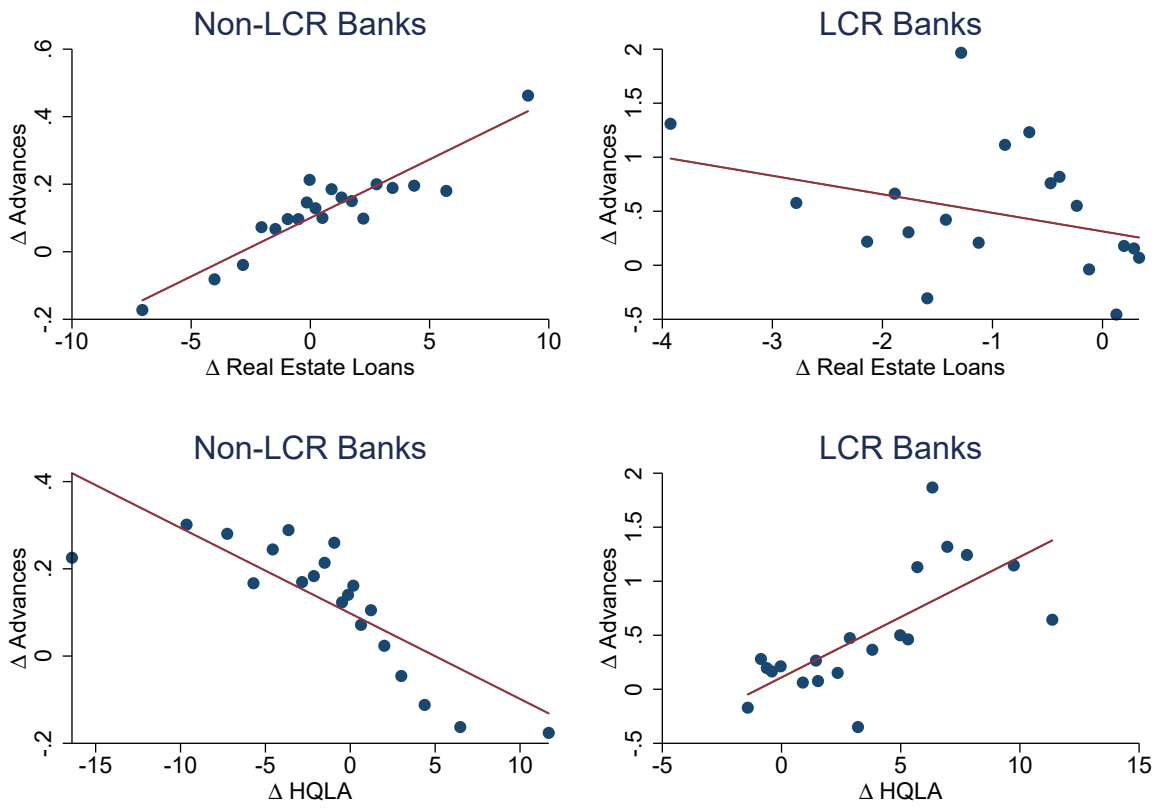

Figure 5: Relation Between Advances, HQLAs, and Real Estate Loans
Graphs 1 and 2 present the binned scatter plots of the change in advances against the change in real estate loans for LCR and non-LCR banks. Graphs 3 and 4 present the binned scatter plots of the change in advances against the change in HQLAs for LCR and non-LCR banks. The sample period is from 2012Q3 to 2014Q4. Data source: FRY-9C and Call report.

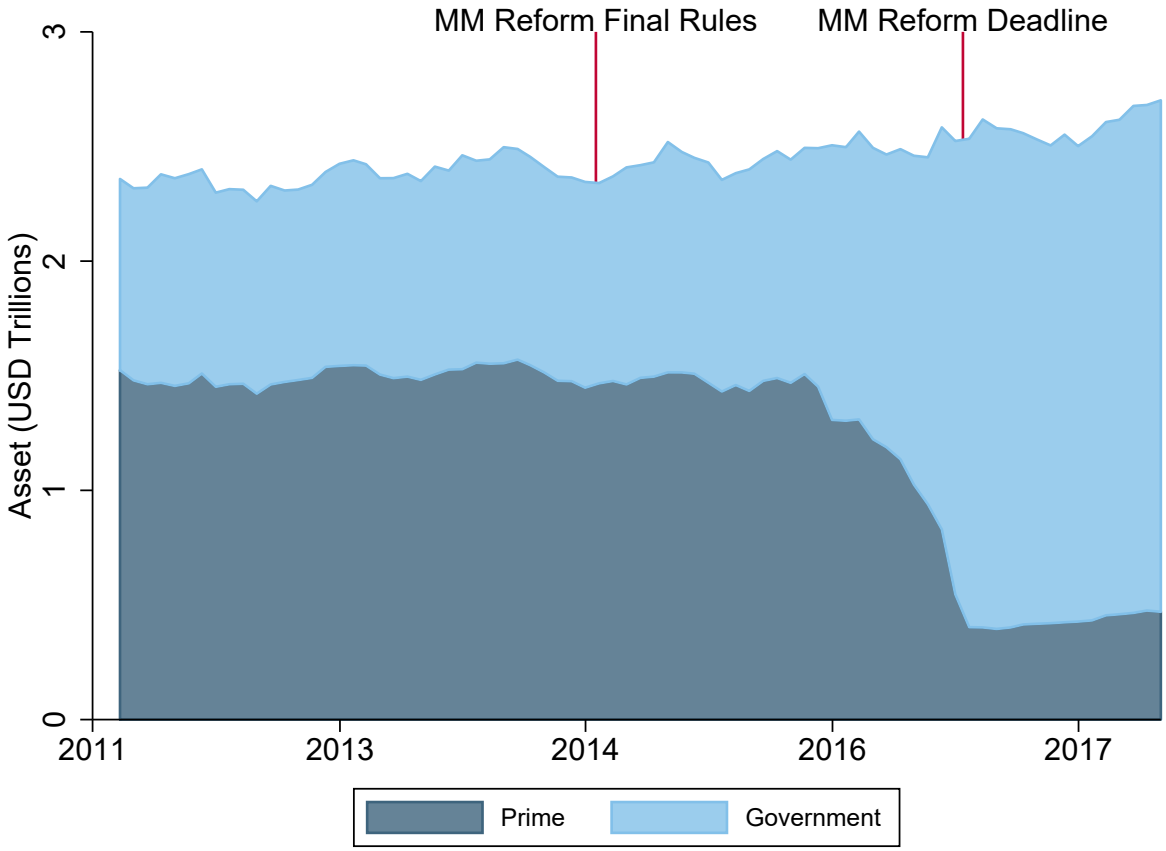

Figure 6: U.S. MMF Assets by Fund Type
This figure plots the amount of assets held by U.S. MMFs for prime and government funds respectively. The sample period is from 2011 to 2017. Data source: iMoneyNet.

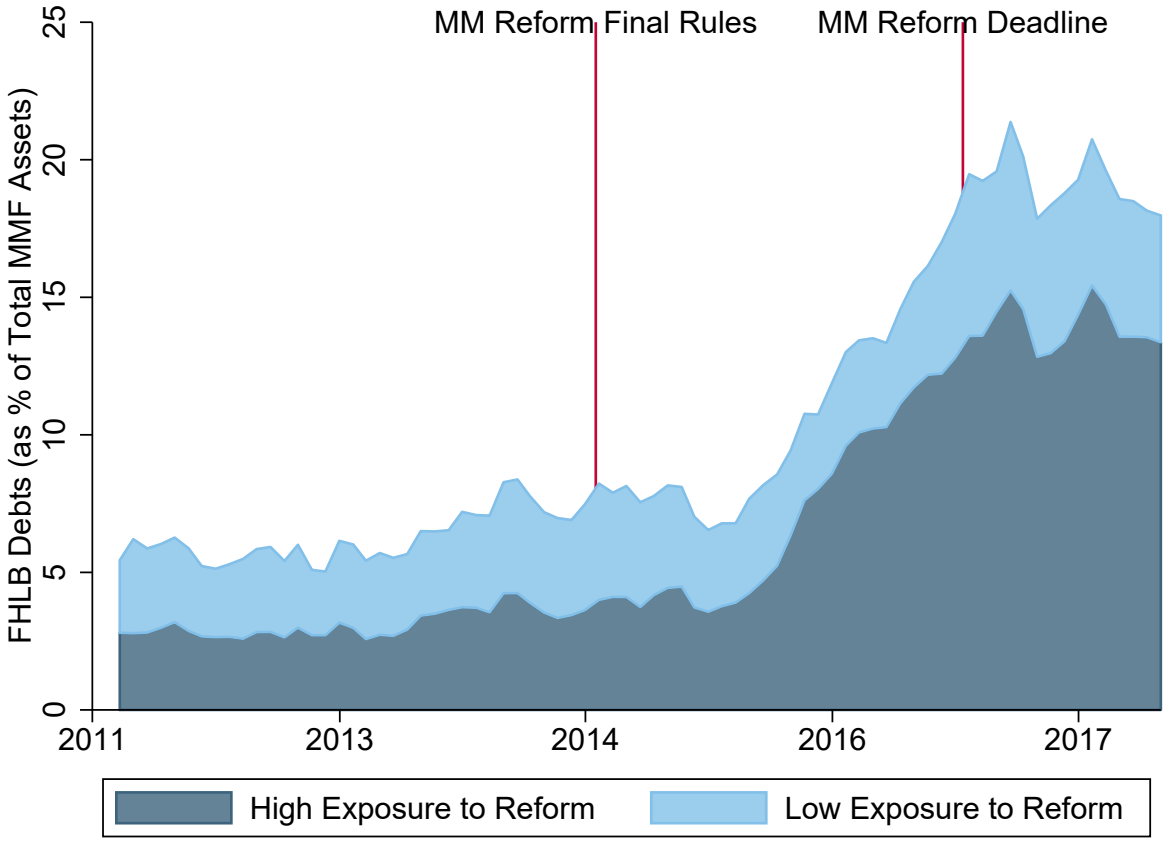

Figure 7: FHLB Debt Held by U.S. MMFs

This graph plots the times series of FHLB debt held by U.S. MMFs as a fraction of the total MMF assets. The red area represents FHLB debt held by fund families that had more than 50% of their assets in prime MMFs in 2014 (high exposure). The blue area represents FHLB debt held by fund families that had less than 50% of their assets in prime MMFs in 2014 (low exposure). Data source: iMoneyNet.

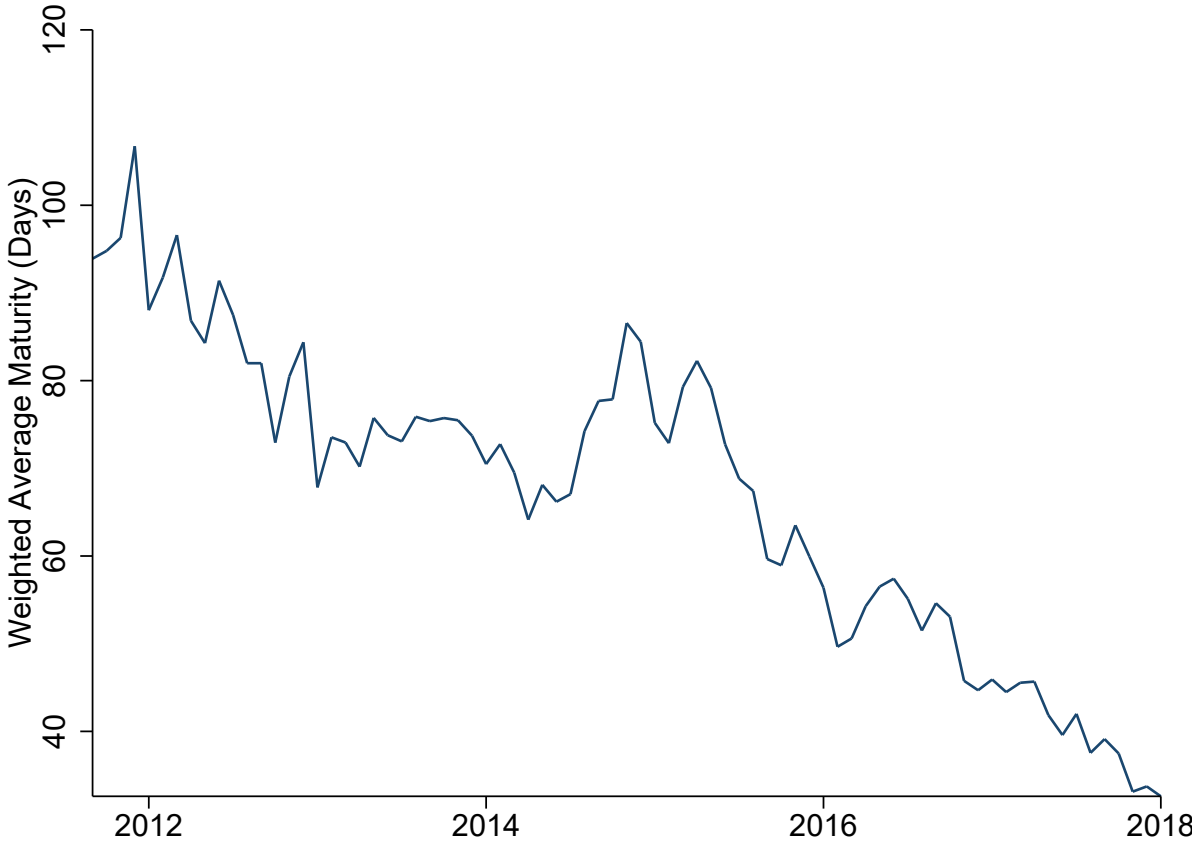

Figure 8: Weighted Average Maturity of MMF Lending to FHLBs
This figure plots weighted average maturity of the MMF lending to the FHLBs. Data source: iMoneyNet.

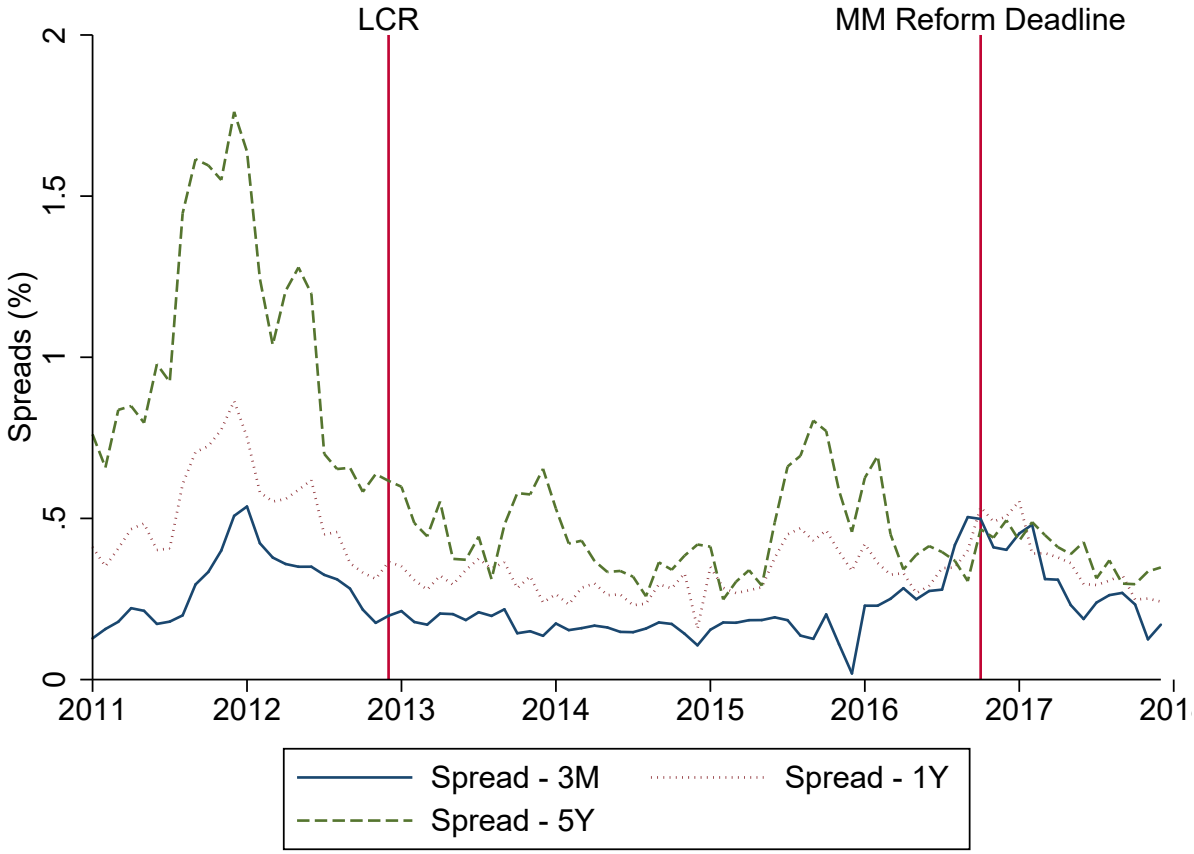

Figure 9: Spreads in Funding Costs: Banks vs. FHLBs
This figure plots the spreads in funding costs between banks and FHLBs from 2011 to 2017. Data source: FHLB Office of Finance and Federal Reserve Bank of St. Louis.

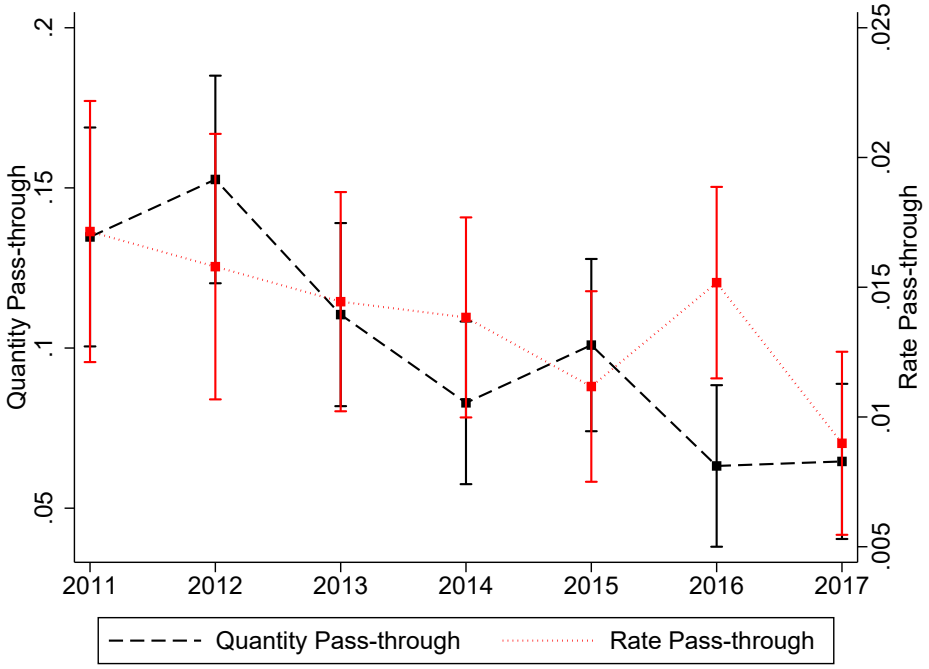

Figure 10: Government Subsidy Pass-Through

This figure plots the rate and quantity pass-through as defined in equation 15. Data source: FHLB Office of Finance, 10-K filing of FHLBs, Call Report.

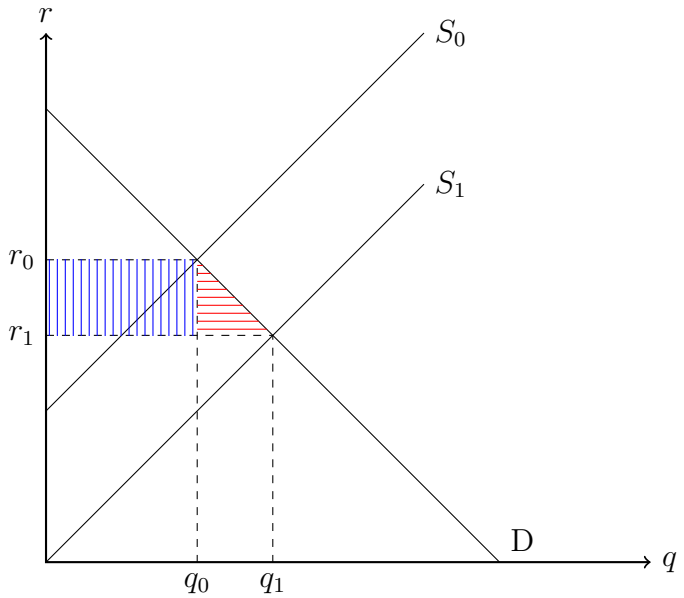

Figure 11: Borrower Surplus due o FHLB Advances

This figure shows borrower surplus in the real estate market. S_0 and S_1 are the supply curves without and with the advances respectively. D is the demand curve. The sum of blue and red region is the increase in borrower surplus due to FHLB advances.

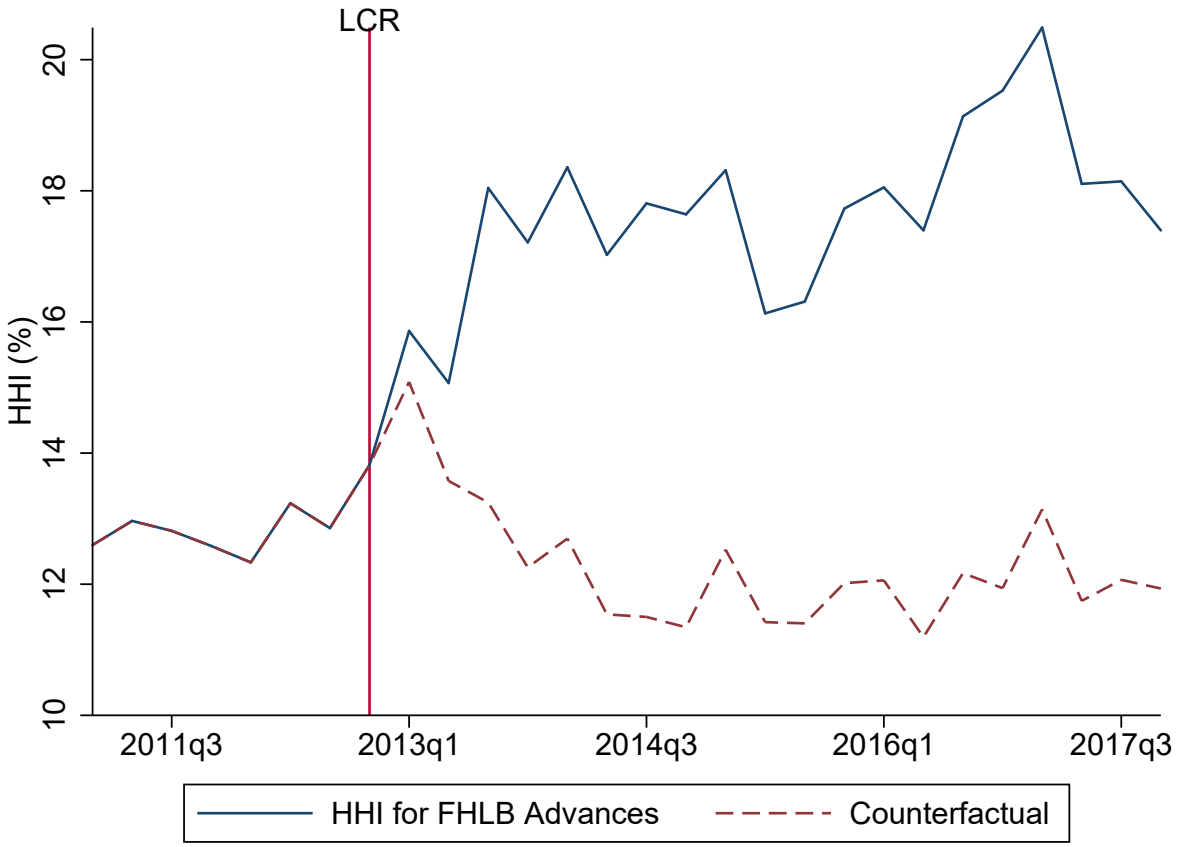

Figure 12: The Herfindahl-Hirschman Index (HHI) of FHLB Lending
This figure plots the HHI of FHLB lending. The counterfactual HHI is computed assuming that the LCR banks' advance-to-asset ratio stays constant after 2012Q4. Data source: Call Report.

Table 1: Summary Statistics

Panel A: Banks

	N	mean	sd	p5	p25	p50	p75	p95
HQLAs	91841	18.444	10.855	3.936	9.764	16.276	25.117	42.432
LCR	91841	1.082	0.784	0.180	0.477	0.862	1.477	2.994
Advances	91841	2.510	3.435	0.000	0.000	0.586	4.179	11.050
Wholesale Funding	91841	4.264	4.351	0.146	0.621	2.688	6.656	14.788
Advances/Wholesale	91841	37.849	39.288	0.000	0.000	24.415	80.485	95.941
Size	91841	19.116	1.334	17.274	18.258	18.974	19.776	21.427
Deposits	91841	84.612	6.269	73.467	81.885	85.894	88.767	91.447
CapitalRatio	91841	10.906	3.336	7.150	9.077	10.340	12.119	16.533
Real Estate Loans	91841	42.024	15.085	14.110	30.838	42.886	53.532	66.985

Panel B: FHLBs

	N	mean	sd	p5	p25	p50	p75	p95
Log Assets	319	18.040	0.472	17.337	17.633	18.036	18.433	18.773
Advances	319	56.865	13.670	26.240	50.655	56.588	68.289	75.762
Securities	319	24.117	9.884	11.842	16.719	21.406	29.464	45.572
Fed Funds Sold	319	5.903	3.996	1.091	3.215	5.091	7.427	14.958
Mortgage Loans	319	6.725	5.869	0.319	1.502	5.837	11.683	16.998
FHLB Notes	319	34.845	12.894	14.529	25.402	34.732	43.886	56.874
FHLB Bonds	319	57.030	12.102	36.037	47.897	57.965	65.540	76.722
Capital Ratio	319	5.219	0.946	3.751	4.709	5.204	5.713	6.709

Panel C: MMFs

	N	mean	sd	p5	p25	p50	p75	p95
FHLB Share	5412	12.038	13.406	0.000	2.295	7.739	17.064	39.532
Log Assets	5412	15.157	2.285	11.768	13.406	14.651	17.158	19.025
Return	5412	0.309	0.272	0.072	0.140	0.204	0.380	1.042
Expense Ratio	5412	0.194	0.137	0.057	0.111	0.160	0.226	0.501
Fund Flow	5412	0.377	16.144	-9.604	-2.401	-0.298	2.075	10.103

Table 2: Effect of LCR Regulation on HQLA Holdings

	(1) HQLA	(2) HQLA	(3) HQLA
Post*LCR Bank	3.551***	3.686***	3.701***
	[1.176]	[1.193]	[1.211]
Post	-0.212	0.275	
	[0.492]	[0.527]	
LCR Bank	17.401***		
	[0.808]		
Log Assets	-0.993***	-3.580***	-3.432***
	[0.077]	[0.614]	[0.495]
Deposit Ratio	0.412***	0.158***	0.136***
	[0.019]	[0.027]	[0.014]
Capital Ratio	0.412***	-0.138*	-0.259***
	[0.016]	[0.070]	[0.052]
Bank F.E.	No	Yes	Yes
Time F.E.	No	No	Yes
Observations	91,841	91,841	91,841
Adj. R-squared	0.056	0.773	0.781

Note: This table shows the impact of the LCR regulations on the amount of HQLAs of U.S. commercial banks. The sample includes all the U.S. banks from 2011Q1 to 2014Q4. The dependent variable, *HQLA*, is the amount of High Quality Liquid Assets normalized by assets. *Post* is a dummy variable that equals 1 if the time is after 2012Q4. *LCR Bank* is a dummy variable that equals 1 if a bank is covered by the full LCR rule in 2012Q4, and 0 otherwise. For control variables, *Log Asset* is the log of the total assets of the bank; *Deposit Ratio* is the ratio of core deposits as a percentage of total deposits of all membership banks; *Capital Ratio* is the ratio of equity as a percentage of total assets of all membership banks; Time and bank fixed effects are added to the regressions as shown in the table. Standard errors shown in parentheses are clustered at the quarter level. ***, **, * represent 1%, 5%, and 10% significance levels, respectively.

Table 3: Effect of the LCR Regulation on FHLB Advances Borrowing

	(1) Advances	(2) Advances	(3) Advances
Post*LCR Bank	1.596***	1.294***	1.294***
	[0.167]	[0.160]	[0.160]
Post	0.076	-0.109	
	[0.065]	[0.063]	
LCR Bank	-5.438***		
	[0.171]		
Log Assets	-0.201***	0.894***	0.910***
	[0.021]	[0.137]	[0.106]
Deposit Ratio	-0.630***	-0.381***	-0.380***
	[0.006]	[0.024]	[0.024]
Capital Ratio	-0.719***	-0.363***	-0.355***
	[0.012]	[0.027]	[0.024]
Bank F.E.	No	Yes	Yes
Time F.E.	No	No	Yes
Observations	91,841	91,841	91,841
Adj. R-squared	0.624	0.881	0.883

Note: This table shows the impact of the LCR regulations on the amount of HQLAs of U.S. commercial banks. The sample includes all the U.S. banks from 2011Q1 to 2014Q4. The dependent variable, *Advances*, is the amount of FHLB advances normalized by assets. *Post* is a dummy variable that equals 1 if the time is after 2012Q4. *LCR Bank* is a dummy variable that equals 1 if a bank is covered by the full LCR rule in 2012Q4, and 0 otherwise. For control variables, *Log Asset* is the log of the total assets of the bank; *Deposit Ratio* is the ratio of core deposits as a percentage of total deposits of all membership banks; *Capital Ratio* is the ratio of equity as a percentage of total assets of all membership banks; Time and bank fixed effects are added to the regressions as shown in the table. Standard errors shown in parentheses are clustered at the quarter level. ***, **, * represent 1%, 5%, and 10% significance levels, respectively.

Table 4: The Impact of MMF Reform on MMF's Lending to the FHLB System

	(1)	(2)	(3)
	% FHLB	% FHLB	% FHLB
Post × Exposure	0.096***	0.088***	0.076***
	[0.010]	[0.010]	[0.010]
Log Assets	-0.176***	0.287***	-2.553***
	[0.044]	[0.055]	[0.450]
Return	6.494***	-70.703***	-62.009***
	[0.984]	[5.261]	[7.664]
Expense Ratio	8.681***	16.045***	6.908***
	[2.302]	[1.664]	[1.791]
Fund Flow	-0.011	-0.008	0.001
	[0.010]	[0.009]	[0.009]
Fund F.E.	N	Y	Y
Time F.E.	N	N	Y
Observations	5,412	5,412	5,412
Adj. R-squared	0.150	0.309	0.709

Note: This table shows the impact of money market reform on MMFs' lending to the FHLB system. The sample includes all money market fund families from January 2011 to December 2017, at that fund family-month level. The dependent variable, % *FHLB Holding*, is the ratio of FHLB assets as a percentage of total assets of the fund family. *Post* is a dummy variable that equals 1 if month is equal to or after July 2014, which was when money market reform rules were finalized. *Exposure* is defined as the fraction of prime fund assets in the fund family. *Post* and *Exposure* are included in the regression when there is no corresponding fixed effects. Control variables include *Log Assets*, *Return*, *Expense Ratio*, and *Fund Flow*, all lagged one month. Time and fund family fixed effects are added as shown in the table. Standard errors are shown in parentheses and are clustered at the month level. ***, **, * represent 1%, 5%, and 10% significance levels, respectively.

Table 5: Maturity Composition of FHLB Advances

	$< 1y$	$\geq 1y$	Total
LCR Banks	37.5	1.1	38.6
Non-LCR Banks	26.1	35.3	61.4
Total	63.6	36.4	100

Note: This table shows fractions of FHLB advances by maturity and by bank type. The sample is from 2012Q4 to 2017Q4. LCR banks are defined as banks with assets above $250 billion in 2012Q4. Non-LCR banks are defined as banks with assets below $50 billion. Data source: Call Report.