The Effects of Liquidity Regulation on Bank Demand for Reserves and Federal Reserve Balance Sheet Policy

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Accessibility
The Effects of Liquidity Regulation on Bank Demand for Reserves
and the Federal Reserve’s Balance Sheet Policy

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Abstract

Over the past two years, high bank demand for reserves has generated volatility in short-term interest rates and impaired the Federal Reserve's ("Fed's") control of the fed funds rate. In this paper, I examine the effect of the Liquidity Coverage Ratio (LCR)—the first standardized minimum liquidity requirement for large U.S. banks—on banks’ reserve demand. I find that the LCR's announcement increased banks’ reserve demand by 67–99%. This implies that to control interest rates, the Fed must maintain a reserve supply $219–325 billion larger than before the LCR. I also estimate that the reserve demand curve shifted out by $170 billion after the LCR’s announcement, although this may not solely reflect the LCR. These results imply that the LCR partly explains the Fed’s reduced control of interest rates but does not explain the majority of the increase in banks’ reserve demand since the financial crisis.

I thank Jeff Miron for his insightful feedback, edits, and advising on my thesis and for all that I have learned from him over the past four years. I am indebted to Ben Friedman and Jeremy Stein for inspiring my interest in monetary policy, and to Michael Blank for sharing his crosswalk files and central banking expertise. I am also grateful for Justin Lee, Cameron Cohen, and Chris Kuang, who invested countless hours in helping me improve my drafts.
1 Introduction

In September 2019, the Fed’s target interest rate, known as the fed funds rate, rose above its target range for the first time since the financial crisis. The culprit was a cash shortage in the “repo” market—where banks lend cash to other firms in exchange for collateral—which caused the repo rate to spike and diverted lending from the fed funds market. Although banks held large quantities of excess reserves, they did not lend enough to keep the funds rate within target, requiring the Fed to purchase assets and lend hundreds of billions of dollars in repo markets for the first time since the financial crisis.

These events are best understood in the context of the Fed’s balance sheet policy. After the 2008 financial crisis, the Fed purchased assets to lower long-term interest rates and credited banks with reserves, increasing the reserve supply from about $10 billion in 2008 to over $2.8 trillion in 2014. Between 2014 and 2017, the Fed kept the reserve supply constant by reinvesting assets as they matured, and in October 2017 it began reducing the reserve supply by slowing these reinvestments.

The Fed did not expect its reduction of the reserve supply to affect short-term interest rates, but in June 2018 the funds rate began to rise. At the time, the reserve supply was $2 trillion, or more than 200 times its pre-crisis level, implying that reserve demand had increased substantially since the financial crisis. To keep the funds rate within its publicly announced target range, the Fed broke with precedent and announced a target range different from the actual range defined by the interest rates at which it borrows from the market. By the time the Fed stopped reducing the reserve supply in August 2019, the funds rate had risen 15 basis points, or more than half a standard rate hike the Fed might use to slow the economy. By underestimating reserve demand, the Fed effectively raised interest rates unintentionally without informing the public.

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1Reserves are a liability for the Fed and an asset for banks (Appendix A.1).

2As I explain later, during quantitative easing, the “saturation level”—the level of reserves at which changes in the reserve supply no longer appreciably affect the funds rate—was about $1 trillion (Reis 2016). Thus, the funds rate’s rise at a reserve supply of $2 trillion indicates that the saturation level had approximately doubled.
Economists have proposed several potential causes of the increase in banks’ reserve demand since the 2008 financial crisis. In particular, they disagree about whether new liquidity regulations, which require banks to hold safe and liquid assets, play a role (Quarles 2018; Ihrig et al., 2019; Logan 2019). Prior research shows that banks subject to the most stringent liquidity regulations also hold the most reserves, but some policymakers argue that this is explained by individual bank preferences, not regulation (Greeley et al., 2019b). In 2018, Fed Vice Chair for Supervision Randal Quarles noted that the Fed did not “have a definitive handle on banks’ long-run demand for reserve balances” and emphasized that research on the effects of liquidity regulation “would be quite valuable to policymakers” (Quarles 2018).

To disentangle the effects of liquidity regulation from other explanations, this paper therefore examines the effect of the first standardized minimum liquidity requirement for large U.S. banks: the Liquidity Coverage Ratio (LCR). The LCR, which became effective in 2015, requires large banks to hold high-quality liquid assets, such as U.S. Treasuries, reserves, and federal agency-backed debt to protect against liquidity shocks. It is the most stringent liquidity regulation adopted after the financial crisis and thus the most likely regulatory cause of the increase in banks’ reserve demand. I analyze the LCR’s effect on reserve demand in two ways.

First, I exploit exogenous variation in the reserve supply to estimate the increase in reserve demand after the LCR’s announcement. I find that the demand curve shifted out by $170 billion, raising the funds rate by 10 basis points, although this may also reflect other factors besides the LCR’s announcement.

Second, I use a difference-in-differences (DD) model to test whether the LCR increased banks’ reserve balances. Although this strategy does not directly estimate the demand curve’s shift, it isolates the LCR’s effect more precisely since it exploits the fact that the LCR requires large banks to hold more high-quality liquid assets than smaller banks. I find that the LCR’s announcement increased the most stringently regulated banks’ reserve
demand by 67–99%, or $219–325 billion, at the interest rates from the post-LCR period.\footnote{I use this value as a rough proxy for the demand curve’s shift, although in reality the demand curve shifted by different amounts at different interest rates. My results also suggest that the LCR may have increased modified LCR banks’ portfolios, but the effect is not statistically significant.} 

Taken together, the results imply that to control interest rates the Fed must maintain a reserve supply about $170–325 billion, or about 17–32 times, larger than before the financial crisis. The LCR thus substantially increased banks’ reserve demand, although it does not explain the majority of the $1 trillion increase since the financial crisis.\footnote{The funds rate began rising in June 2018 at a reserve supply of about $2 trillion. As I explain later, during QE, the funds rate reached its effective lower bound at a reserve supply of about $1 trillion, implying that the “saturation level” of reserves at which changes in the reserve supply no longer affect the funds rate has increased by about $1 trillion since the financial crisis. This implies that, to maintain control of the funds rate, the Fed must maintain a reserve supply about $1 trillion larger than before the financial crisis. The LCR does not explain the majority of this increase.} Other kinds of regulation, the Fed’s payment of interest on reserves, and changes in banks’ preferences for liquidity may explain the rest. The Fed should consider all of these factors when calibrating the reserve supply.

Congress passed the LCR in an attempt to improve financial stability, and most prior research addresses it from this perspective. However, my results show that the LCR also has important implications for monetary policy. In an attempt to improve financial stability, policymakers may have unintentionally undermined the conduct of monetary policy and generated financial volatility. The LCR thus provides important insight into the unintended consequences of regulation.

This paper is organized as follows. In the next section, I review the fed funds market, the structure of the LCR, and recent developments in funding markets and monetary policy. In Section\footref{sec:fedfunds} I discuss the data. In Section\footref{sec:reserves} I exploit exogenous variation in the reserve supply to estimate the reserve demand curve’s shift after the LCR’s announcement. In Section\footref{sec:dd} I use the DD model to estimate the LCR’s effect on regulated banks’ reserve balances and report robustness checks. Section\footref{sec:conclusion} concludes.
Banks use reserves to settle transactions, meet internal liquidity targets, and comply with regulations. They borrow and lend reserves overnight to other banks and certain non-bank institutions, such as government-sponsored enterprises, in the fed funds market. Figure 1 depicts the market. The reserve supply curve is vertical because it is determined by the Fed. The demand curve is downward-sloping and convex because as the reserve supply expands, banks increasingly have enough reserves to settle transactions and meet liquidity needs (Bräuning 2018; Marquez et al., 2013). When the reserve supply is below the “saturation level” of reserves, supply intersects the demand curve on its downward-sloping portion, so changes in the reserve supply affect the funds rate.\(^5\) When the reserve supply is above the saturation level, changes in supply do not appreciably affect the funds rate, which remains at its “effective lower bound” (ELB).\(^6\)

\(^5\)The saturation level is a useful concept, although its definition somewhat arbitrary in practice. Beyond some quantity of reserves, the demand curve is flat for the purposes of monetary policy.

\(^6\)I depict the “effective lower bound” (ELB) for the funds rate as small but nonzero. Beyond the saturation level of reserves, the slope of the reserve demand curve is close to zero, so the funds rate is small but nonzero at the saturation level. However, for the purposes of this paper, the ELB is synonymous with the “zero lower bound” (ZLB).
During QE, the Fed increased the reserve supply from $10 billion to $2.8 trillion. Source: Board of Governors of the Federal Reserve System, Factors Affecting Reserve Balances (H.4.1)

Before the 2008 financial crisis, the reserve supply was below saturation, and the Fed controlled the funds rate through open market operations: shifting the reserve supply curve along the downward-sloping portion of the demand curve. The Fed lowered the funds rate by purchasing assets to increase the reserve supply and raised the funds rate by selling assets to reduce the reserve supply.\footnote{The Fed can also create non-reserve liabilities. However, in conducting the asset purchases that I discuss in this paper, the Fed disproportionately increased the reserve supply rather than creating other kinds of liabilities.}

In response to the 2008 financial crisis, the Fed purchased large quantities of assets through its “quantitative easing” (QE) program, expanding the reserve supply from about $10 billion in 2008 to over $2.8 trillion in 2014 (Figure 2). The reserve supply reached saturation at about $1 trillion in 2011, when the funds rate reached the ELB (Reis 2016) (Figure 3).

Since the reserve supply was above saturation, the Fed could no longer use open market operations to effectively raise interest rates unless it first quickly sold large quantities of assets, which would risk an economic contraction. Congress authorized the Fed to pay
banks interest on reserve balances at the end of 2008, which became the cornerstone of a new mechanism for controlling the funds rate (Board of Governors 2015). In December 2008 the Fed began targeting a range of 25 basis points for the funds rate. The interest rate the Fed pays banks on their reserve balances, known as the “interest on reserves” or “interest on excess reserves” (IOER) rate, defined the top of the target range. The “overnight reverse repurchase agreement” (ON-RRP) rate, which the Fed pays banks and non-bank counterparties in secured overnight transactions, defined the bottom of the range.

Figure 4 illustrates the relationship between the funds rate, the IOER rate, and the ON-RRP rate. When the reserve supply is above saturation, the funds rate is generally below the IOER rate. Non-banks in the fed funds market cannot earn the IOER rate on reserves, so they lend at rates below it when demand is sufficiently low (Williamson 2016). Since banks hold large reserve balances when the supply is above saturation, they generally do not borrow to settle transactions, comply with regulations, or meet liquidity needs. Instead, banks borrow reserves from non-banks to deposit them with the Fed and earn IOER, arbitraging the spread between the IOER rate and the funds rate. The arbitrage strategy pushes the funds rate close to the IOER rate, but transaction costs prevent perfect

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8Before 2008, the Fed targeted a specific funds rate, rather than a range.
9In theory, the Fed could pay banks different interest rates on their required and excess reserves. In practice, however, the Fed has always paid the same interest rate for required and excess reserves. The Board of Governors refers to the tool as the IOER, so I use that acronym in this paper.
arbitrage, so the funds rate remains several basis points below the IOER rate. The ON-RRP rate provides a lower bound for the funds rate because no participant in the fed funds market is willing to lend at rates below it. Between 2011 and 2017, when the reserve supply was above saturation, the funds rate was about 10 basis points below the IOER rate.

Figure 4: The Fed Funds Rate, IOER, and ON-RRP

If the reserve supply falls below saturation, however, the funds rate rises and can exceed the IOER rate since the supply curve intersects the demand curve on its downward-sloping portion. As the reserve supply decreases, banks increasingly borrow reserves to settle transactions and comply with regulations, causing the funds rate to rise. If the funds rate exceeds the IOER rate, then the IOER–ON-RRP range no longer bounds the funds rate.

In October 2017, the Fed began reducing the reserve supply by slowing its reinvestment of assets purchased during QE. Policymakers did not intend the reduction to affect short-term interest rates, but the effective fed funds rate (EFFR) equaled the IOER rate in October 2018 and exceeded it in March 2019 (Yellen 2017). The funds rate began rising in March 2018 at a reserve supply of $2 trillion, or double the $1 trillion saturation level reached in 2011, implying that reserve demand had increased substantially since the financial crisis, which is the focus of this paper (Figure 5).
The effective fed funds rate (EFFR) is the Fed’s target interest rate. The EFFR exceeded the IOER rate in 2019. Source: Federal Reserve Bank of St. Louis

By September 2019, the balance sheet reduction had raised the funds rate by 15 basis points, or more than half of a standard rate hike the Fed might use to slow the economy. The repo rate’s spike in the same month caused the funds rate to exceed the IOER rate by 20 basis points and rise above the Fed’s official target range for the first time. By underestimating banks’ reserve demand, the Fed had effectively raised interest rates unintentionally during a period of below-target inflation without informing the public.

### 2.2 Recent Monetary Policy

Over the past two years, the Fed has announced several abrupt policy changes to maintain control of the funds rate. First, even as it continued reducing the reserve supply, the Fed broke with precedent and publicly announced a different target range for the funds rate than the actual range between the IOER rate and the ON-RRP rate. I refer to the publicly announced range as the “verbal target range.” Although the funds rate rose above the range defined by the IOER and ON-RRP in March 2019, it remained within the verbal target...
The verbal target range is the target range for the effective fed funds rate (EFFR) that the Fed announces to the public. *Source: Federal Reserve Bank of St. Louis*

range until September (Figure 6).¹⁰

Second, when the funds rate first equaled the IOER rate in March 2019, the Fed announced that it would end its balance sheet reduction program in September of that year. Between March and September, however, the funds rate rose further above the IOER rate as the Fed continued reducing the reserve supply, prompting a second Fed announcement in July that it would instead end the balance sheet reduction in August.

Finally, in response to the funds rate’s rise above the verbal target range in September 2019, the Fed lent hundreds of billions in repo markets to keep the funds rate within target. In October of the same year, only two months after the Fed ended the balance sheet reduction, the Fed restarted asset purchases to increase the reserve supply.

¹⁰Figure 6 does not depict the fed funds rate rising above the verbal target range because it plots the average weekly funds rate, and the funds rate exceeded the verbal target range for only one day.
2.3 Explanations for Increased Reserve Demand

Economists have proposed several causes, both transient and permanent, of the increase in banks’ reserve demand. Possible explanations include the Fed’s payment of interest on reserve balances, banks’ revisions of their internal liquidity targets, higher risk aversion, and financial regulations. In an August 2019 Fed survey of Senior Financial Officers at 77 banks, most respondents indicated that the most important factor determining their lowest comfortable level of reserves was the ability to meet routine intraday payment flows (Board of Governors 2019a). However, this does not necessarily explain the majority of banks’ actual reserve balances.

In particular, economists debate whether regulations, such as the LCR and liquidity stress tests, play a role. Some bank executives claim that regulatory constraints prevented banks from lending in the repo market when interest rates spiked in September 2019 (Scuffham and Schroeder 2019). Philadelphia Fed President Patrick Harker has argued it is “worth asking if regulation might be contributing” to the sudden rise in repo rates (Quarles 2018; Ihrig et al., 2019; Greeley et al., 2019a). Boston Fed President Rosengren argues, however, that there is “no evidence” that regulations increased banks’ reserve demand because different banks subject to the same regulations often hold quite different reserve balances (Greeley et al., 2019b). Quarles (2018) explains that the Fed does not “have a definitive handle on banks’ long-run demand for reserve balances” and that the current saturation level of reserves is “highly speculative.” He calls for additional research on the topic, which is the focus of this paper.

2.4 The Liquidity Coverage Ratio (LCR)

The LCR is the first standardized minimum liquidity requirement for large U.S. banks. It requires large banks to maintain an adequate stock of high-quality liquid assets (HQLA) to meet liquidity needs during a 30-day stress scenario. The Basel Committee on Banking Supervision finalized the LCR rule in January 2013, and in September 2014 the Fed im-
implemented the LCR in accordance with Section 165 of the Dodd-Frank Act, which requires the Fed Board of Governors to develop liquidity requirements for banks with more than $50 billion in assets.

HQLA include a range of liquid assets categorized by their approximate degree of liquidity. Level 1 comprises the most liquid assets, such as excess reserves and Treasury securities. Level 2 assets include the debt and mortgage-backed securities of government sponsored enterprises, plus corporate debt securities; they cannot account for more than 40% of total HQLA and are subject to large haircuts in valuation. The “Liquidity Coverage Ratio” is the ratio of the value of a bank’s HQLA stock in stressed conditions to the total net cash outflows the bank would experience over a 30-day liquidity stress scenario. The standard LCR requires banks with more than $250 billion in assets (“standard LCR banks”) to maintain an LCR of at least 100%, and the modified LCR requires banks with between $50 billion and $250 billion in assets (“modified LCR banks”) to maintain an LCR of at least 70%.

The motivation of the LCR is to improve financial stability, and most prior research addresses it from this perspective. Adrian and Boyarchenko (2014) show that in a DSGE model in which liquidity and capital regulation interact with the supply of risk-free assets, minimum liquidity requirements lower the likelihood of systemic distress without impairing consumption growth. Li et al. (2017) show that under certain theoretical conditions the LCR decreases credit creation in financial stress scenarios. Roberts et al. (2019) find that the LCR has real economic costs: after the Basel Committee finalized the LCR rule, banks subject to it created less liquidity and lent less than others.

In this paper, I examine the LCR’s effects on the conduct of monetary policy. Previous literature on the topic includes Bech and Keister (2017), who show that under certain theoretical conditions the LCR can increase bank reserve demand and impair the Fed’s control of interest rates. Greenwood et al., (2016) warn that if the LCR is too stringent it can constrain monetary policy since the Fed cannot increase the total supply of HQLA through open market operations. Ihrig et al., (2019) show that the reserve shares of LCR-regulated
banks have risen after the LCR, but they do not provide quantitative or causal estimates of the LCR’s effect. Rezende et al. (2016) find that the LCR increases banks’ participation in the Federal Reserve’s Term Deposit Facility operations; this is related to, but distinct from, reserve demand.

I focus on the LCR for several reasons. First, it is the most stringent liquidity regulation adopted in the post-crisis period, so it is the most likely regulatory cause of banks’ higher reserve demand. Second, a priori reasoning suggests the LCR may have increased banks’ reserve demand: Large banks, the most stringently regulated by the LCR, hold a disproportionate share of reserve balances (Ihrig 2019). Third, policymakers announced the LCR in 2013, making it possible to estimate the announcement’s effect on reserve demand while abstracting from the turbulence of the financial crisis. Finally, the LCR is presumably permanent, implying that if it increased banks’ reserve demand, then at any interest rate the Fed must maintain a permanently larger reserve supply.

The LCR does not specifically require banks to increase their reserve balances, so it is not obvious ex ante that it increases banks’ reserve demand. Since Treasuries and reserves are both Level 1 HQLA, banks could meet the HQLA requirement with Treasuries. There are several reasons, however, why banks likely allocate a fraction of their HQLA portfolios to reserves. First, since the LCR’s announcement the IOER rate has often exceeded Treasury yields (Appendix A.2). Second, only reserves guarantee intraday liquidity to manage stress scenarios or routine payment flows, and they do not expose banks to interest rate risk since they have zero maturity (Quarles 2020; Logan 2019). Treasuries also carry some credit

\footnote{With sufficiently granular data, one could estimate the extent to which banks find reserves and Treasuries substitutable by measuring the extent to which exogenous increases in the T-bill supply affect banks’ reserve balances. Given that publicly available data on banks’ reserve balances is quarterly, however, I do not have sufficiently granular data to conduct this analysis. This is a potential area for further research for Federal Reserve Economists.}

\footnote{To test the hypothesis that banks hold reserves largely for liquidity purposes, I regress a daily series of the EFFR-IOER spread on end-of-month dummies, end-of-quarter dummies, and end-of-year dummies, since demand for liquidity often increases during these periods due to taxes and regulations. I find that the end of the month significantly predicts a decrease in the EFFR-IOER spread. This likely reflects banks decreasing their borrowing in the fed funds market to avoid regulatory fees charged in proportion to their balance sheet sizes at the end of each month, so it is difficult to detect end-of-month increases in demand for liquidity. Controlling for the end of the month, neither the end of the quarter nor the end of the year...}
Finally, although the LCR does not discriminate between reserves and Treasuries, private feedback from Fed supervisors caused “many banks [to believe] the Fed preferred [reserves] over Treasuries” (Stacey and Noonan 2019; Scuhham and Schroeder 2019). Quarles (2020) notes that Fed supervisors expect firms to estimate their day-one outflows during a stress scenario, which can most effectively be met with reserves.

3 Data

I merge multiple datasets to create a consolidated quarterly dataset of balance sheet characteristics for individual banks. Data on U.S. banks’ identifying information, their parent bank holding companies, and all balance sheet characteristics, such as reserve balances, assets, loans, and trading activities come from the Federal Financial Institutions Examination Council (FFIEC) reporting forms 041 and 031. FFIEC form 031, the “Consolidated Reports of Condition and Income for a Bank with Domestic and Foreign Offices,” includes balance sheet characteristics of all state member banks that have branches or subsidiaries located in a foreign country. FFIEC form 041, the “Consolidated Reports of Condition and Income for a Bank with Domestic Offices Only,” includes balance sheet characteristics of state member banks with domestic offices only. Banks are required to file the applicable report.

Since the LCR regulates bank holding companies, I merge bank-level data by bank holding company to create a new dataset of balance sheet characteristics at the bank holding company level. Throughout this paper, I refer to bank holding companies as “banks.”

Weekly Fed balance sheet data, such as assets, reverse repurchase operations, currency in circulation, and the Treasury General Account (TGA) balance come from the Federal

\footnote{Significantly predicts a change in the EFFR-IOER spread, suggesting that changes in demand for intraday liquidity at these intervals may not substantially affect banks’ borrowing or lending in the fed funds market (Appendix A.3).}

\footnote{For example, in August 2011, Standard & Poor’s downgraded the credit rating of U.S. Treasury debt from AAA to AA+ after Congress voted to raise the federal government’s debt ceiling.}

\footnote{I thank Michael Blank for contributing a key that matches commercial banks to their “parent” banks below the bank holding company level, if any, in order to subtract redundant data reported by both “parent” and “child” commercial banks.}

Following the National Bureau of Economic Research’s (NBER’s) classification, I consider the financial crisis to end in June 2009, so I estimate my regressions beginning in 2010 to abstract from crisis-era effects. I estimate the DD model over 2010–2017 because Congress exempted banks with less than $100 billion in assets from the LCR in May 2018 (Board of Governors 2018). Following Roberts et al., (2019), I exclude banks with less than $3 billion in assets from the sample because they are too different from LCR banks to provide a reasonable control group. I also exclude foreign banks because they did not report data until 2016 (Roberts et al., 2019).

I define the LCR’s announcement period as the first two quarters of 2013. The Basel Committee finalized the LCR rule in January 2013, and policymakers publicly stated that they would implement the LCR beginning in February 2013 (Tarullo 2013; Stein 2013a). By the second quarter of 2013, Fed officials explicitly stated that U.S. banking agencies would soon issue a plan to implement the LCR rule and the Federal Open Market Committee explicitly referred to “forthcoming changes in bank liquidity regulation” that would require larger banks to hold higher quantities of liquid assets (Stein 2013b; Federal Open Market Committee 2013). I assume that banks became aware that the Fed would soon implement the LCR during the first two quarters of 2013. Thus, I define the pre-LCR announcement period as 2010 Q1–2012 Q4, the during-LCR announcement period as 2013 Q1–2013 Q2, and the post-LCR announcement period as 2013 Q3–2017 Q4.

\[15\]

Banks with less than $3 billion in assets are generally regional and traditional: they take deposits from the local population, provide loans to local firms, are not active in capital markets, and rely on little market funding.

\[16\]

This broadly conforms to the existing literature. For example, Roberts et al. (2019) consider the LCR’s announcement period to be the second quarter of 2013, but I use the first two quarters of 2013 because Fed officials publicly stated they would implement the LCR during the first quarter of 2013.
4 Estimating the Reserve Demand Curve

4.1 Methodology

I first exploit exogenous variation in the reserve supply to estimate the reserve demand curve’s shift after the LCR’s announcement. I assume that the spread between the effective fed funds rate (EFFR) and the IOER rate is a hyperbolic function of the quantity of reserves demanded:\footnote{I use a hyperbolic functional form because it is consistent with the empirical evidence that the funds rate is a decreasing function of the quantity of reserves and flattens as the quantity of reserves increases (Marquez et al., 2013). In the monetary policy literature, the reserve demand curve is also frequently drawn as “kinked” or roughly hyperbolic. The asymptote of the hyperbolic function approximates the concept of the saturation level. See, for example, Bräuning (2018), Frost (1971), and Reis (2016).}

\[
P = \beta_0 + \beta_1 \frac{1}{Q_D} + \epsilon
\]

where \( P \) is the EFFR-IOER spread and \( Q_D \) is the quantity of reserves demanded.\footnote{The EFFR-IOER spread measures changes in the funds rate not driven by changes in the IOER rate, which represents the funds rate’s distance from the upper bound of its target range.} In equilibrium, \( Q_D = Q_S \), where \( Q_S \) is the quantity of reserves supplied, implying:

\[
P = \beta_0 + \beta_1 \frac{1}{Q_S} + \epsilon
\]

Since the Fed might preemptively adjust the reserve supply if it expects the funds rate to change due to funding market conditions, the reserve supply is likely endogenous with respect to the EFFR-IOER spread. Following Bräuning (2018), I use the U.S. Treasury General Account (TGA) balance—the U.S. Treasury’s transaction account held with the Fed—as an instrument for the reserve supply (Appendix A.1.1).
Figure 7: Weekly Change in TGA Balance

The Treasury General Account (TGA) is the U.S. Treasury’s transaction account held with the Fed. 
*Source: Board of Governors of the Federal Reserve System, Factors Affecting Reserve Balances (H.4.1)*

Figure 7 plots weekly changes in the TGA balance, which are driven by the Treasury’s ordinary operations, such as paying federal employees and receiving tax revenue. The TGA balance is exogenous because it is unrelated to monetary policy or conditions in short-term funding markets.\(^{19}\)

The TGA balance is correlated with the reserve supply because both are liabilities for the Fed (Appendix A.1.1). Holding the Fed’s assets and other liabilities constant, an increase in the TGA balance implies an equal decrease in the reserve supply. This is shown by the Fed’s balance sheet identity:

\[
\text{Assets} = \text{Currency} + \text{Reserves} + \text{RRP} + \text{TGA}
\]

where *Currency* is the total value of Federal Reserve notes in circulation, *Reserves* is the reserve supply, and *RRP* is the volume of the Fed’s reverse repurchase (“reverse repo”).\(^{19}\)

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\(^{19}\) This is strictly true only when controlling for Treasury bill issuance, which affects short-term interest rates and may correlate with the TGA balance through fiscal policy (Huther et al., 2019). My instrumental variables strategy largely follows Bräuning (2018), but he does not control for assets, currency, or Treasury bill issuance.
facilities. Following Bräuning (2018), I exclude smaller liabilities. The identity implies:

\[
Reserves = Assets - Currency - RRP - TGA
\]

Holding the Fed’s assets and other liabilities constant, \( \Delta Reserves = -\Delta TGA \). For example, when the Treasury pays employees, the TGA balance decreases and reserves increase, but this change is unrelated to short-term interest rates. Table 1 displays the first-stage regression of \( \frac{1}{Reserves_t} \) on \( \frac{1}{TGA_t} \).

Table 1: First Stage Regression

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>1/Reserves (billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/TGA (billions)</td>
<td>-0.00004*** (0.00002)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.001*** (0.00001)</td>
</tr>
</tbody>
</table>

Observations 572
R\(^2\) 0.008
Adjusted R\(^2\) 0.006
Residual Std. Error 0.0003 (df = 570)
F Statistic 4.392** (df = 1; 570)

Note: *p<0.1; **p<0.05; ***p<0.01

I use the TGA balance as an instrument for the reserve supply to estimate the reserve demand curve over 2009-2019, allowing for shifts during and after the LCR’s announcement. The regression model is:

\[
Spread_t = \beta_0 + \beta_1 \mathbb{I}(\text{DuringLCR}_t) + \beta_2 \mathbb{I}(\text{PostLCR}_t) + \beta_3 \frac{1}{TGA_t} \\
+ \beta_4 \left[ \mathbb{I}(\text{DuringLCR}_t) \frac{1}{TGA_t} \right] + \beta_5 \left[ \mathbb{I}(\text{PostLCR}_t) \frac{1}{TGA_t} \right] \\
+ \beta_6 Assets_t + \beta_7 Currency_t + \beta_8 RRP_t + \beta_9 TBills_t + \beta_{10} Time_t + \epsilon_t \quad (1)
\]
where $1(DuringLCR_t)$ is an indicator for the LCR announcement period (2013 Q1 and 2013 Q2), $1(PostLCR_t)$ is an indicator for the period after the LCR’s announcement, $Spread_t$ is the EFFR-IOER spread, and $TBills_t$ is the Treasury’s net issuance of short-term debt (“T-bills”). The TGA balance is likely correlated with the EFFR-IOER spread through the Fed’s reverse repo volume, $RRP_t$, because banks may borrow cash overnight through reverse repo agreements when their reserve balances decline (Bräuning 2018). I control for $Time_t$ to remove common linear time trends between variables. I adjust the EFFR-IOER spread and TGA balance for seasonality.\textsuperscript{20}

### 4.2 Results

Table \textsuperscript{2} displays the coefficients of the reserve demand curve; the coefficients that measure the demand curve’s shift after the LCR’s announcement are significant at the 0.001 level.\textsuperscript{21} The demand curve’s intercept is about 10 basis points higher after the LCR’s announcement, an increase equivalent to nearly half a standard rate hike that the Fed might use to slow the economy. The effect of the $\frac{1}{TGA_t}$ term after the LCR’s announcement is about 800 times larger than before the announcement, implying that the demand curve was substantially steeper afterward. This is likely because the reserve supply was near or above the saturation level during 2009–2012.\textsuperscript{22} Although the demand curve shifted by different amounts at different values of the reserve supply, at reasonable values the EFFR-IOER spread increased by close to 10 basis points, so I use the intercept shift as a rough proxy for the demand curve’s overall shift.

\textsuperscript{20}I adjust for seasonality by regressing the EFFR-IOER spread and TGA balance on quarterly and monthly dummy variables, because taxes and regulations may cause demand for overnight loans and the TGA balance to spike at these times.

\textsuperscript{21}The results contrast with Logan (2019), who argues that, as of April 2019, there was no discernible relationship between changes in the reserve supply and the EFFR-IOER spread.

\textsuperscript{22}I cannot estimate the slope of the demand curve before this period because before the financial crisis, the Treasury limited the volatility of the TGA balance and the Fed actively managed the reserve supply to counteract changes in the TGA balance, so the TGA balance was not exogenous until the end of 2008, when the Fed began to pay IOER (Huther et al., 2019).
Table 2: Reserve Demand Curve Model

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EFFR-IOER spread (bps)</td>
<td></td>
</tr>
<tr>
<td>During-LCR announcement</td>
<td>3.207*</td>
<td>(1.643)</td>
</tr>
<tr>
<td>Post-LCR announcement</td>
<td>6.554***</td>
<td>(0.908)</td>
</tr>
<tr>
<td>1/TGA (billions)</td>
<td>-0.324*</td>
<td>(0.196)</td>
</tr>
<tr>
<td>During-LCR announcement * 1/TGA</td>
<td>-138.905</td>
<td>(89.602)</td>
</tr>
<tr>
<td>Post-LCR announcement * 1/TGA</td>
<td>-105.510***</td>
<td>(24.822)</td>
</tr>
</tbody>
</table>

| Observations | 569      |
| R²           | 0.808    |
| Adjusted R²  | 0.804    |
| Residual Std. Error | 2.486 (df = 558) |
| F Statistic  | 234.712*** (df = 10; 558) |

*Note:* *p<0.1; **p<0.05; ***p<0.01

To obtain a measure of the demand curve’s shift in terms of reserves, I re-estimate Equation 1 but switch \( \text{Spread}_t \) and \( TGA_t \) (Appendix A.4.1). The intercept of the post-LCR demand curve is about $170 billion higher than that of the pre-LCR demand curve, implying that the reserve supply must remain much larger than its $10 billion average before the financial crisis.

23 I estimate the “flipped” regression, rather than computing the change in reserves from points along the demand curve estimated by Equation 1 to calculate the intercept shift of the demand curve in terms of reserves, which is a useful summary of the demand curve’s overall shift. Although this regression runs counter to causal intuition, it can be shown that it estimates the reserve demand curve as long as the instrumental variables exclusion restriction holds for Equation 1, which I justified above.

24 The TGA balance’s variance is large relative to that of the EFFR-IOER spread, because the TGA balance is driven by the Treasury’s everyday operations, such as paying employees. As a result, the coefficient on the terms of interest in this regression are not significant, unlike for Equation 1. As a result, I use the intercept as a ballpark point estimate of the demand curve’s shift in terms of the reserve supply.
The demand curve’s shift after the LCR’s announcement cannot be exclusively attributed to the LCR. It may overestimate the LCR’s effect if, for example, other liquidity requirements or capital regulation also increased reserve demand during the LCR’s announcement period. It may underestimate the LCR’s effect if banks’ risk aversion or expectations of risk declined during the LCR’s announcement period, decreasing reserve demand. However, the model provides a rough estimate of the LCR’s effect on reserve demand.

5 Difference-in-Differences

Next, I use a difference-in-differences (DD) model to examine whether the LCR increased regulated banks’ reserve demand. Although this strategy does not directly estimate the reserve demand curve, it more precisely isolates the LCR’s effect since it compares treatment and control groups.

5.1 Motivation

The LCR’s structure lends itself to a DD approach in which the treatment occurs during the first two quarters of 2013, when the Fed announced that it would soon implement the LCR. The strategy relies on the fact that the LCR regulates large banks more stringently than small and medium-sized banks. Banks with more than $250 billion in assets (“standard LCR banks”) are subject to the standard LCR, those with between $50 billion and $250 billion in assets (“modified LCR banks”) are subject to the modified LCR, and those with less than $50 billion in assets (“non-LCR banks”) have no HQLA requirement.

Figure 8 plots the average reserves-to-assets ratios (“reserve shares”) of standard LCR, modified LCR, and non-LCR banks controlling for time fixed effects, which reflects the

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25 I discuss these regulations in the next section.
26 As a rough proxy for banks’ risk aversion or expected risk, I re-estimate the demand curve’s shift, controlling for market volatility as measured by the Chicago Board Options Exchange Volatility Index (VIX). The results of this regression are reported in Appendix A.4.2 including VIX does not appreciably change my results.
redistribution of reserves among bank groups holding the reserve supply constant. Before the LCR’s announcement the reserve shares of each of the three groups followed a broadly similar trend; after the LCR’s announcement, however, the reserve shares of regulated banks (and especially that of standard LCR banks) increased relative to unregulated banks, suggesting the LCR may have increased regulated banks’ reserve demand.

5.2 Comparing LCR-Regulated Banks to Non-LCR Banks

First, I use the DD model to estimate the LCR’s effect on regulated banks’ reserve shares. I estimate all regressions over 2010–2017. The model relies on the identifying assumption that absent the LCR, the reserves-to-assets ratios of LCR-regulated banks (“LCR banks”) would have followed the same trend as those of non-LCR banks; I discuss this assumption at the end of this section.

I examine whether the reserve shares of LCR banks diverged from those of non-LCR banks after the LCR’s announcement:
\[
\text{ReserveShare}_{it} = \beta_0 + \beta_1 \mathbb{1}(LCRBank_i) + \beta_2 \left[ \mathbb{1}(\text{DuringLCR}_t) * \mathbb{1}(LCRBank_i) \right] + \beta_3 \left[ \mathbb{1}(\text{PostLCR}_t) * \mathbb{1}(LCRBank_i) \right] + \phi_t + \epsilon_{it}
\]

where \( \text{ReserveShare}_{it} \) is a bank’s reserves-to-assets ratio, \( \mathbb{1}(LCRBank_i) \) is an indicator for LCR banks, \( \mathbb{1}(\text{DuringLCR}_t) \) is an indicator for the LCR announcement period (2013 Q1 and 2013 Q2), \( \mathbb{1}(\text{PostLCR}_t) \) is an indicator for the period after the LCR’s announcement, \( \phi_t \) are time fixed effects, and \( \epsilon_{it} \) is the error term.

I cluster standard errors by bank. The coefficient of interest is \( \beta_3 \), which measures the LCR’s effect on LCR banks’ reserve shares. Time fixed effects control for changes in the reserve supply, so the coefficient of interest reflects the redistribution of reserves after the LCR’s announcement.

I also control for pre-existing trends in the difference between LCR banks’ and non-LCR banks’ reserve shares in two ways. First, I nonparametrically control for the three quarters preceding the “during-LCR” period by interacting quarter dummies with an indicator for LCR banks. The regression equation is:

\[
\text{ReserveShare}_{it} = \beta_0 + \beta_1 \mathbb{1}(LCRBank_i) + \beta_2 \left[ \mathbb{1}(\text{DuringLCR}_t) * \mathbb{1}(LCRBank_i) \right] + \beta_3 \left[ \mathbb{1}(\text{PostLCR}_t) * \mathbb{1}(LCRBank_i) \right] + \sum_{j=3}^{5} \beta_{4j} \left[ (L^j \mathbb{1}(\text{PostLCR}_t) * \mathbb{1}(LCRBank_i)) \right] + \phi_t + \epsilon_{it}
\]

where \( L^j \) is the lag operator applied \( j \) times, and \( j \) ranges from 3 to 5 since the pre-LCR period ends three quarters before the post-LCR period begins (because two “during-LCR” quarters precede the post-LCR period).

Second, I control for a pre-existing linear trend in the difference between LCR banks’ and non-LCR banks’ reserve shares. The regression equation is:
$\text{ReserveShare}_{it} = \beta_0 + \beta_1 \mathbb{1}(L\text{CRBank}_{it}) + \beta_2 [\mathbb{1}(\text{DuringLRC}_t) * \mathbb{1}(L\text{CRBank}_{it})] + \beta_3 [\mathbb{1}(\text{PostLRC}_t) * \mathbb{1}(L\text{CRBank}_{it})] + \beta_4 L\text{CRBankTrend}_{it} + \phi_t + \epsilon_{it}$ (4)

where $L\text{CRBankTrend}_{it}$ is the interaction between $\mathbb{1}(L\text{CRBank}_{it})$ and a continuous time variable.

Table 3: DD: LCR vs. Non-LCR Banks

<table>
<thead>
<tr>
<th></th>
<th>(1) Reserve Share</th>
<th>(2) Reserve Share</th>
<th>(3) Reserve Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-LCR announcement * LCR bank</td>
<td>0.027**</td>
<td>0.035**</td>
<td>0.027**</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.011)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>LCR bank</td>
<td>0.031</td>
<td>0.035</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td>(0.018)</td>
<td>(0.020)</td>
<td>(0.018)</td>
</tr>
<tr>
<td>Non-LCR bank * time</td>
<td>-0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dependent variable mean</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Time fixed effects</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Control for three leads</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control for linear trend</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>No pre-trend controls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>5509</td>
<td>5509</td>
<td>5509</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.097</td>
<td>0.097</td>
<td>0.096</td>
</tr>
</tbody>
</table>

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Data source: Federal Financial Institutions Examination Council (FFIEC) Forms 031 and 041. Notes: A bank’s reserve share is the ratio of its reserves to its assets. Post-LCR announcement is an indicator variable for the period after the LCR’s announcement. LCR banks are banks with more than $50$ billion in assets at the time the LCR rule was finalized, which are subject to the LCR. Standard errors are in parentheses (clustered by bank).

Table 3 reports the results. In every specification, I estimate that LCR banks’ reserve shares increased by roughly 3 percentage points; the coefficients of interest are statistically significant at the 0.01 level. Before the LCR’s announcement the average bank with more than $50$ billion in assets held 7.4% of its assets in reserves, implying that the LCR increased
LCR banks’ reserve shares by nearly 50%.

5.3 Comparing Standard Banks, Modified LCR Banks, and Non-LCR Banks

Next, I use a similar model to estimate the LCR’s effect on regulated banks’ reserve shares, now separating banks into three groups: standard LCR, modified LCR, and non-LCR. I estimate:

\[
ReserveShare_{it} = \beta_0 + \beta_1 \mathbb{1}(ModLCRBank_i) + \beta_2 \mathbb{1}(StdLCRBank_i) + \beta_3 \mathbb{1}(DuringLCR_t) \ast \mathbb{1}(ModLCRBank_i) \\
+ \beta_4 \mathbb{1}(PostLCR_t) \ast \mathbb{1}(ModLCRBank_i) \\
+ \beta_5 \mathbb{1}(DuringLCR_t) \ast \mathbb{1}(StdLCRBank_i) \\
+ \beta_6 \mathbb{1}(PostLCR_t) \ast \mathbb{1}(StdLCRBank_i) \\
+ \phi_t + \epsilon_{it}
\] (5)

where \( \mathbb{1}(ModLCRBank_i) \) is an indicator for modified LCR banks, \( \mathbb{1}(StdLCRBank_i) \) is an indicator for standard LCR banks, \( \mathbb{1}(DuringLCR_t) \) is an indicator for the LCR announcement period (2013 Q1 and 2013 Q2), \( \mathbb{1}(PostLCR_t) \) is an indicator for the period after the LCR’s announcement, \( \phi_t \) are time fixed effects, and \( \epsilon_{it} \) is the error term. The coefficients of interest are \( \beta_4 \) and \( \beta_6 \), which measure the LCR’s effect on the reserve shares of modified LCR banks and standard LCR banks.

I also control for pre-existing trends in two ways. First, I nonparametrically control for the three quarters preceding the LCR’s announcement by interacting quarter dummies with an indicator for bank regulatory group, as in Equation 3. Second, I control for a pre-existing linear trend in the difference between LCR banks’ and non-LCR banks’ reserve shares, as in
Table 4: DD: Standard LCR vs. Modified-LCR vs. Non-LCR Banks

<table>
<thead>
<tr>
<th></th>
<th>(1) Reserve Share</th>
<th>(2) Reserve Share</th>
<th>(3) Reserve Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-LCR announcement * Modified LCR bank</td>
<td>0.016 (0.012)</td>
<td>0.019 (0.010)</td>
<td>-0.002 (0.008)</td>
</tr>
<tr>
<td>Post-LCR announcement * Standard LCR bank</td>
<td>0.030* (0.015)</td>
<td>0.044* (0.022)</td>
<td>0.040** (0.018)</td>
</tr>
<tr>
<td>Modified LCR bank * time</td>
<td>-0.000 (0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard LCR bank * time</td>
<td>-0.000 (0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dependent variable mean</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Time fixed effects</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Control for three leads</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control for linear trend</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>No pre-trend controls</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Observations</td>
<td>5509</td>
<td>5509</td>
<td>5509</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.089</td>
<td>0.088</td>
<td>0.087</td>
</tr>
</tbody>
</table>

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Data source: Federal Financial Institutions Examination Council (FFIEC) Forms 031 and 041. Notes: A bank's reserve share is the ratio of its reserves to its assets. Post-LCR announcement is an indicator variable for the period after the LCR's announcement. Standard LCR banks are those with more than $250 billion in assets at the time the LCR rule was finalized, which are subject to the standard LCR rule. Modified LCR banks are those with $50–250 billion in assets at the time the LCR rule was finalized, which are subject to the weaker, modified LCR rule. Standard errors in parentheses (clustered by bank).

Table 4 reports the results. In the specifications that control for pre-trends (Columns 1 and 2), I estimate that the LCR increased standard LCR banks’ reserve shares by 3.0–4.4 percentage points, but the 95% confidence intervals for the coefficient of interest are compatible with both large and very small effects. Before the LCR’s announcement, the average bank with more than $250 billion in assets held 4.5% of its assets in reserves, suggesting

The 95% confidence interval for the first specification, which controls for pre-existing trends in the three preceding quarters, is [0.002, 0.059]. The 95% confidence interval for the first specification, which controls for a pre-existing linear trend, is [0.0001, 0.0880]. Both confidence intervals are thus compatible with minuscule and large increases in reserve shares (nearly 0–200 percentage points). Thus, while both specifications are most consistent with substantial increases in reserve shares (67 and 99 percentage points) and rule out the possibility of no effect at the 0.05 level, they cannot rule out values that are low enough to have little practical importance.
the LCR increased standard LCR banks’ reserve shares by 67–99%. I also estimate that the LCR increased modified banks’ reserve shares by 1–2 percentage points, but the coefficient of interest is not statistically significant in any of the specifications.

The increase in standard LCR banks’ reserve shares translates to $219–325 billion in reserves, implying that reserve demand increased by that amount at the interest rates from the post-LCR period.\footnote{In reality, the demand curve may have shifted out by different amounts at different interest rates; the estimates also do not measure the demand curve’s shift at interest rates other than those that prevailed after the LCR’s announcement. I assume that modified LCR banks’ reserve demand did not increase since the increase is not statistically significant.}

5.4 Validity and Robustness Checks

The DD model relies on the identifying assumption that absent the LCR, the reserves-to-assets ratios of more stringently regulated banks would have followed the same trend as those of less stringently regulated banks. This assumption seems reasonable because absent regulatory changes, a bank’s demand for reserves to settle transactions and meet liquidity needs likely depends on broad economic conditions, rather than its size. In this section, I provide suggestive evidence against potential threats to validity. Despite these robustness checks, however, I cannot rule out the possibility that my estimates are not causal.

Parallel Trends

If the identifying assumption is true, a likely corollary is that the reserves-to-assets ratios of more stringently regulated banks would follow the same trend as those of less stringently regulated banks before the LCR’s announcement. In this section, I show that before the LCR’s announcement:

1. The reserves-to-assets ratio of LCR banks broadly followed the same trend as that of non-LCR banks;
2. The reserves-to-assets ratio of modified LCR banks broadly followed the same trend as that of non-LCR banks;

3. The reserves-to-assets ratio of standard LCR banks increased relative to that of modified LCR banks, although statistical tests show that it increased most significantly after the LCR’s announcement and my results are robust to controlling for this pre-trend.

Figure 9: LCR Banks’ – Non-LCR Banks’ Reserve Shares

Note: Controls for time fixed effects. The red dashed line marks the LCR’s announcement. Source: Federal Financial Institutions Examination Council (FFIEC) Forms 031 and 041.

Figure 9 depicts the average difference in LCR banks’ and non-LCR banks’ reserve shares controlling for time fixed effects, which reflects the redistribution of a fixed quantity of reserves between LCR and non-LCR banks. LCR banks’ reserve shares decreased relative to those of non-LCR banks before the LCR’s announcement and increased sharply afterward.\(^{29}\)

\(^{29}\)The difference between LCR banks’ and non-LCR banks’ reserve shares began decreasing in 2015, possibly reflecting the rise of T-bill rates compared to the IOER rate (Appendix A.2); larger banks may disproportionately take advantage of changes in relative yields because they have a greater ability to flexibly expand or contract their balance sheets and may face lower transaction costs.
Figure 10: Modified LCR Banks’ – Non-LCR Banks’ Reserve Shares

Figure 10 depicts the average difference in modified LCR banks’ and non-LCR banks’ reserve shares. Although the data are noisy, modified LCR banks’ reserve shares decreased compared to those of non-LCR banks before the LCR’s announcement but increased afterward.

Figure 11 depicts the average difference in standard LCR banks’ and modified LCR banks’ reserve shares. Although standard LCR banks’ reserve shares increased substantially compared to those of modified LCR banks after the LCR’s announcement, they also increased before the LCR’s announcement, which casts doubt on the validity of the identifying assumption. As previously discussed, however, my coefficient of interest for standard LCR banks remains significant when controlling for pre-trends, and the coefficients of the controls are insignificant in each specification.
To further examine the pre-trends, I re-estimate the DD regressions that control for linear pre-trends (Equation 4 and its counterpart for all three regulatory groups) under the counterfactual assumption that the treatment occurred in each of the two final pre-LCR quarters (2012 Q3 and 2012 Q4). The coefficient of interest is insignificant in every regression, suggesting that banks’ reserve shares did not begin to diverge substantially until the first two quarters of 2013 (Appendix A.5.1). The Quandt likelihood ratio test also confirms that the divergence between standard LCR banks’ and modified LCR banks’ reserve shares was most significant in 2013 Q1 and that the divergence between modified LCR banks’ and non-LCR banks’ reserve shares was most significant in 2013 Q2. Both dates are within the “during-LCR announcement” period. Both structural breaks are significant at the 0.05 level (Appendix A.5.2).  

30 The F-statistic for the QLR test of a structural break in the difference between standard LCR banks’ and modified LCR banks’ reserve shares in 2013Q1 is 65.176, and the p-value is approximately zero. The F-statistic for the QLR test of a structural break in the difference between modified LCR banks’ and non-LCR banks’ reserve shares in 2013Q2 is 8.89, and the p-value is 0.048.
Placebo Tests

If the identifying assumption is true, another likely corollary is that bank characteristics not directly affected by the LCR do not diverge after the LCR’s announcement. To test this corollary, I run several placebo tests, replacing the dependent variable in my regressions with bank characteristics that the LCR likely does not affect, such as equity swaps, foreign exchange swaps, interest rate swaps, loans to foreign banks, and loans to other depository institutions, each as a share of banks’ assets (Appendix A.5.3). The coefficient of interest is insignificant in every regression.

Omitted Variables: Sensitivity to QE

One potential concern with the identification strategy is that the coefficient of interest is confounded by the effects of the Fed’s QE asset purchases, which occurred between 2008 Q4 and 2014 Q2. Large banks may be able to more elastically expand their liabilities to fund higher reserve balances, so they may have absorbed a disproportionate share of the reserves created during QE compared to small banks. If so, LCR banks’ increased reserve shares may reflect QE rather than the LCR. To test this explanation, I compare the change in banks’ reserve balances during QE to their change during the balance sheet reduction (2017 Q3 – 2019 Q4). If LCR banks disproportionately increased their reserve balances in 2013 because they were better able to absorb new reserves, I would expect their reserve balances to disproportionately decrease, ceteris paribus, during the Fed’s balance sheet reduction.31

To examine whether LCR banks’ reserve shares disproportionately changed during QE and the balance sheet reduction, I calculate an “elasticity score” for each bank over the two periods. A bank’s elasticity score is the change in its reserves-to-assets ratio divided by the change in the banking system’s ratio over the same period.32

31 This may not hold if banks’ reserve demand has structurally changed since QE for other reasons. I address the main candidates for such changes later in this section. At a minimum, finding a strong correlation between banks’ balance sheet expansions during QE and their balance sheet reductions during the Fed’s balance sheet reduction suggests that my DD results may be biased upward, but the lack of such a finding does not necessarily imply the reverse.

32 I thank Michael Blank for the inspiration for this method. The “banking system” refers to the sum of
Elasticity Score = \frac{\Delta \text{Bank Reserves}}{\Delta \text{Bank Assets}} \times \frac{\Delta \text{Banking System Reserves}}{\Delta \text{Banking System Assets}}

A bank having an absolute score greater than one implies that the its reserves-to-assets ratio changed more than that of the banking system, and a bank having a positive score implies that its reserves-to-assets ratio changed in the same direction as that of the banking system.

Figure 12: Elasticity Scores of LCR Banks and Non-LCR Banks During QE and the Fed’s Balance Sheet Reduction

A bank’s elasticity scores capture how flexibly it expanded its reserve balances compared to the aggregate banking system during QE and the Fed’s balance sheet reduction. Source: Federal Financial Institutions Examination Council (FFIEC) Forms 031 and 041.

Figure 12 displays a scatterplot of banks’ elasticity scores in both periods. Neither LCR banks’ nor non-LCR banks’ reserve shares appear sensitive to changes in the reserve supply; both groups’ elasticity scores cluster around one. Within each bank group, there is also little correlation between the two elasticity scores (and the correlation between LCR banks’ elasticity scores for the two periods is negative), suggesting that the banks that expanded their reserve balances the most during QE did not necessarily decrease their reserve balances all banks in my dataset, which includes all U.S. bank holding companies for which data on reserves or assets were available.
the most during the balance sheet reduction. Thus, it does not appear that the increase in LCR banks’ reserve shares is driven by greater flexibility in expanding their balance sheets.

**Omitted Variables: Other Regulations**

Another concern with the identification strategy is that my estimates are confounded by other regulations that treat large banks differently than small banks.

The main potential regulatory confounder is the Fed’s resolution planning requirement: in 2013 the Fed required modified LCR banks to submit resolution plans to “demonstrate that they hold sufficient liquid assets to meet outflows in stressed scenarios and in resolution,” which may have motivated them to hold more liquid assets (Ihrig 2019; Quarles 2020). To the extent that the resolution planning requirement caused modified LCR banks to increase their reserve balances, my regressions may overestimate the LCR’s effect on modified LCR banks’ reserve shares, but since I do not find that the LCR significantly affected modified LCR banks, it would not substantially change my results.

Capital constraints also may have increased banks’ reserve demand. Since reserves carry a zero risk weight, LCR banks with binding risk-based capital ratios may have increased their reserve balances in accordance with the Fed’s 2013 Comprehensive Capital Analysis and Review (CCAR) of banks with more than $50 billion in assets (Ihrig et al., 2019; Board of Governors 2013). However, the CCAR required banks to submit capital plans and company-run stress test results by January 2013, and the Fed objected to the plans of only two banks, so most banks likely completed the majority of their portfolio adjustments before the LCR’s announcement period.

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33. Although the Fed finalized the requirement in 2011, the Fed required banks with between $100 billion and $250 billion in assets to submit their resolution plans by July 2013 and those with between $50 billion and $100 billion in assets to submit their resolution plans by December 2013 (“Federal Reserve Board Approves Final Rule Implementing the Resolution Plan Requirement of the Dodd-Frank Act.” Board of Governors of the Federal Reserve System, 17 Oct. 2011).

34. In addition, the two banks to whose capital plans the Fed objected are modified LCR banks. If they continued to adjust their capital portfolios into the LCR announcement period, it would not appreciably change my results, since I do not find that the LCR significantly affected modified LCR banks’ reserve demand.
Further, even if the CCAR or the resolution planning requirement biases my estimates, it would not change the policy implications of this paper. I argue that if the LCR increased banks’ reserve demand, then at any interest rate the reserve supply must remain permanently larger than before the LCR. The argument also applies to other regulations that permanently increase banks’ reserve demand.

Another potential concern with the identification strategy is that policymakers may have chosen the LCR’s size thresholds because they believed that absent the LCR, bank size would correlate with specific outcomes that in turn correlate with banks’ reserve shares, such as access to liquidity. This is unlikely, however: the $50 billion and $250 billion size thresholds are common to many regulations in the Dodd-Frank Act. Further, even if policymakers expected large banks to hold fewer liquid assets absent the LCR, it would decrease my coefficient of interest and make my results more conservative.

6 Conclusion

As the Fed has reduced the reserve supply over the past two years, high bank demand for reserves has impaired the Fed’s control of the fed funds rate. In 2018, to keep the funds rate within its publicly announced target range, the Fed broke with precedent and announced a target range different from the actual range defined by the interest rates at which it borrows from the market. By underestimating reserve demand, the Fed effectively raised interest rates unintentionally during a period of below-target inflation without informing the public.

Economists have proposed several potential causes of the increase in banks’ reserve demand, including liquidity regulation that requires or encourages banks to hold more safe, liquid assets. This paper has examined the effect of the most stringent liquidity regulation, the Liquidity Coverage Ratio (LCR), on banks’ reserve demand.

I estimate that the reserve demand curve shifted out by $170 billion after the LCR’s announcement, raising the funds rate by 10 basis points, although this may not solely reflect
the LCR. I also estimate that the LCR increased the most stringently regulated banks’ reserve shares by 67–99%, which translates to a $219–325 billion increase in reserve demand at the interest rates from the post-LCR period.

The LCR thus partly explains the Fed’s reduced control of the fed funds rate over the past two years, which slowed the economy at a time when the inflation rate was already consistently below the Fed’s target. But since the funds rate began to rise when the reserve supply was near $2 trillion and the saturation level during QE was only $1 trillion, the LCR does not explain the majority of the increase in banks’ reserve demand since the financial crisis.

By requiring the Fed to maintain a permanently larger balance sheet to control interest rates, the LCR resolves an ongoing debate among economists about whether the benefits of a large balance sheet outweigh its costs. Proponents claim that a large reserve supply, and therefore a large balance sheet, can improve financial stability by increasing the supply of safe, liquid assets and crowding out private issuance of short-term debt, which is vulnerable to systemic risk (Greenwood et al., 2016). Opponents argue that a large balance sheet may justify excessive intervention in financial markets by allowing the Fed to buy or sell large quantities of assets to control credit conditions in particular industries. This, in turn, could threaten the Fed’s independence by blurring the lines between fiscal and monetary policy (Plosser 2017; Taylor 2018). In this paper, I show that the to control interest rates, the Fed must maintain a larger balance sheet, resolving this debate.

The LCR’s effect on banks’ reserve demand illustrates the importance of considering policies’ unintended consequences before their implementation: in an attempt to improve financial stability, policymakers may have unintentionally impaired the conduct of monetary policy and raised interest rates during a period of below-target inflation.
A Appendix

A.1 Federal Reserve and Bank Balance Sheets

A.1.1 Federal Reserve Balance Sheet

Table 5: Federal Reserve Balance Sheet

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Securities held outright:</td>
<td>Currency</td>
</tr>
<tr>
<td>U.S. Treasury securities</td>
<td>Reserves</td>
</tr>
<tr>
<td>Federal agency debt</td>
<td>Reverse repurchase agreements</td>
</tr>
<tr>
<td>Mortgage-backed securities</td>
<td>Treasury General Account</td>
</tr>
<tr>
<td>Other securities</td>
<td>Other deposits</td>
</tr>
<tr>
<td>Repurchase agreements</td>
<td>Other liabilities</td>
</tr>
<tr>
<td>Loans to banks</td>
<td></td>
</tr>
<tr>
<td>Other assets</td>
<td></td>
</tr>
</tbody>
</table>

A.1.2 Bank Balance Sheet

Table 6: Bank Balance Sheet

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities and Equity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash</td>
<td>Deposits</td>
</tr>
<tr>
<td>Reserves</td>
<td>Debt</td>
</tr>
<tr>
<td>Investments</td>
<td>Other liabilities</td>
</tr>
<tr>
<td>Loans</td>
<td>Total shareholders’ equity</td>
</tr>
<tr>
<td>Other assets</td>
<td></td>
</tr>
</tbody>
</table>
A.2 IOER and T-Bill Rates

Figure 13: IOER rate and T-Bill Rates (2013-2019)

Source: Federal Reserve Bank of St. Louis.
### A.3 Test for Seasonal Liquidity Demand

Table 7: Regression on end-of-month, end-of-quarter, and end-of-year dummies

<table>
<thead>
<tr>
<th>Dependent variable: EFFR-IOER spread (bps)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>End of month</td>
<td>-0.012**</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
</tr>
<tr>
<td>End of quarter</td>
<td>-0.011</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
</tr>
<tr>
<td>End of year</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.067***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observations</th>
<th>1,287</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.010</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.007</td>
</tr>
<tr>
<td>Residual Std. Error</td>
<td>0.061 (df = 1283)</td>
</tr>
<tr>
<td>F Statistic</td>
<td>4.174*** (df = 3; 1283)</td>
</tr>
</tbody>
</table>

*Note:* *p<0.1; **p<0.05; ***p<0.01
# A.4 Demand Curve Model

## A.4.1 TGA vs. Spread

Table 8: Demand Curve (TGA balance as dependent variable)

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>TGA balance (billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During-LCR announcement</td>
<td>142.369 (114.575)</td>
</tr>
<tr>
<td>Post-LCR announcement</td>
<td>24.174 (19.845)</td>
</tr>
<tr>
<td>1/Spread (bps)</td>
<td>41.391 (37.392)</td>
</tr>
<tr>
<td>During-LCR announcement * 1/Spread</td>
<td>-1,569.558 (1,496.929)</td>
</tr>
<tr>
<td>Post-LCR announcement * 1/Spread</td>
<td>-39.638 (37.441)</td>
</tr>
</tbody>
</table>

| Observations | 569 |
| R² | 0.679 |
| Adjusted R² | 0.673 |
| Residual Std. Error | 65.292 (df = 558) |
| F Statistic | 117.829*** (df = 10; 558) |

*Note:*

* p<0.1; ** p<0.05; *** p<0.01
### A.4.2 Control for VIX

Table 9: Demand Curve (controls for VIX)

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EFFR-IOER spread (bps)</td>
</tr>
<tr>
<td>During-LCR announcement</td>
<td>3.266**</td>
</tr>
<tr>
<td></td>
<td>(1.644)</td>
</tr>
<tr>
<td>Post-LCR announcement</td>
<td>6.492***</td>
</tr>
<tr>
<td></td>
<td>(0.910)</td>
</tr>
<tr>
<td>1/TGA (billions)</td>
<td>−0.294</td>
</tr>
<tr>
<td></td>
<td>(0.198)</td>
</tr>
<tr>
<td>During-LCR announcement * 1/TGA</td>
<td>−139.228</td>
</tr>
<tr>
<td></td>
<td>(89.592)</td>
</tr>
<tr>
<td>Post-LCR announcement * 1/TGA</td>
<td>−101.785***</td>
</tr>
<tr>
<td></td>
<td>(25.065)</td>
</tr>
</tbody>
</table>

Observations 569  
R² 0.808  
Adjusted R² 0.805  
Residual Std. Error 2.485 (df = 557)  
F Statistic 213.526*** (df = 11; 557)

Note: *p<0.1; **p<0.05; ***p<0.01
A.5 DD Robustness Checks
A.5.1 Falsification Tests

Table 10: DD Falsification Test: Counterfactual Treatment in 2012 Q3

<table>
<thead>
<tr>
<th></th>
<th>(1) Reserves/total assets</th>
<th>(2) Reserves/total assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-2012 Q3 * LCR Bank</td>
<td>-0.01</td>
<td>-0.00</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>Non-LCR bank * time</td>
<td>0.00*</td>
<td>-0.00</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>Post-2012 Q3 * Standard LCR Bank</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.02)</td>
<td></td>
</tr>
<tr>
<td>Standard LCR bank * time</td>
<td>-0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>37362</td>
<td>37362</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.025</td>
<td>0.012</td>
</tr>
</tbody>
</table>

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11: DD Falsification Test: Counterfactual Treatment in 2012 Q4

<table>
<thead>
<tr>
<th></th>
<th>(1) Reserves/total assets</th>
<th>(2) Reserves/total assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-2012 Q4 * LCR Bank</td>
<td>-0.00</td>
<td>-0.00</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>Non-LCR bank * time</td>
<td>0.00*</td>
<td>-0.00</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>Post-2012 Q4 * Standard LCR Bank</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.02)</td>
<td></td>
</tr>
<tr>
<td>Standard LCR bank * time</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>37362</td>
<td>37362</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.025</td>
<td>0.012</td>
</tr>
</tbody>
</table>

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
A.5.2 QLR Tests

Figure 14: QLR Test: Standard LCR - Modified LCR Banks’ Reserve Shares

Note: The horizontal red line displays the F statistic corresponding to a p-value of 0.05. The black vertical line marks the time of the most significant structural change. The maximum F statistic is 65.176, with a p-value of 0.000.

Figure 15: QLR Test: Standard LCR - Modified LCR Banks’ Reserve Shares

Note: The horizontal red line displays the F statistic corresponding to a p-value of 0.05. The black vertical line marks the time of the most significant structural change. The maximum F statistic is 8.89, with a p-value of 0.048.
### Table 12: Placebo Tests

<table>
<thead>
<tr>
<th></th>
<th>(1) Interest rate swaps</th>
<th>(2) Equity swaps</th>
<th>(3) Forex swaps</th>
<th>(4) Loans to foreign banks</th>
<th>(5) Loans to depos. instit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-LCR announcement * LCR bank</td>
<td>11.57 (11.56)</td>
<td>0.00 (0.00)</td>
<td>-1.54 (1.78)</td>
<td>-0.01 (0.01)</td>
<td>-0.00 (0.00)</td>
</tr>
<tr>
<td>LCR bank</td>
<td>19.42 (19.58)</td>
<td>0.00 (0.00)</td>
<td>2.01 (1.28)</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>LCR bank * time</td>
<td>-1.12 (1.13)</td>
<td>-0.00 (0.00)</td>
<td>0.02 (0.07)</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>Observations</td>
<td>39901</td>
<td>39901</td>
<td>39901</td>
<td>35050</td>
<td>40867</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.069</td>
<td>0.001</td>
<td>0.144</td>
<td>0.027</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Standard errors in parentheses (clustered by bank). Dependent variables are shares of banks’ total assets. All specifications control for time fixed effects.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
B References


____. 2018. “Federal Reserve Board Issues Statement Describing How, Consistent with Recently Enacted EGRRCPA, the Board Will No Longer Subject Primarily Smaller, Less Complex Banking Organizations to Certain Board Regulations.”


