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The Effects of Liquidity Regulation on Bank Demand in Monetary Policy Operations

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Abstract

We estimate the effects of the liquidity coverage ratio (LCR), a liquidity requirement for banks, on the tenders that banks submit in Term Deposit Facility operations, a Federal Reserve tool created to manage the quantity of bank reserves. We identify these effects using variation in LCR requirements across banks and a change over time that allowed term deposits to count toward the LCR. Banks subject to the LCR submit tenders more often and submit larger tenders than exempt banks when term deposits qualify for the LCR. These results suggest that liquidity regulation affects bank demand in monetary policy operations.

JEL Codes: E52, E58, G21, G28

Key words: Liquidity Coverage Ratio, Term Deposit Facility, Monetary Policy, Excess Reserves, Basel III

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1 Introduction

In response to the recent financial crisis, many countries have adopted liquidity regulations. Academics and policymakers, however, have argued that liquidity regulation may affect bank behavior, thereby interfering with monetary policy (Cœuré, 2013; Gagnon and Sack, 2014; Bech and Keister, 2015; Committee on the Global Financial System and Markets Committee, 2015; Duffie and Krishnamurthy, 2016; Potter, 2016). In particular, some monetary policy tools remove liquidity from the banking system, but liquidity regulation requires that banks hold liquid assets, which may affect their demand in monetary policy operations. This interaction could lead to less-effective policy tools and weakened financial stability. Although there is some recent theoretical work in this area, to our knowledge, there is no empirical evidence of a causal effect of liquidity regulation on bank demand in monetary policy operations.

This paper attempts to fill this gap by estimating the effects of the liquidity coverage ratio (LCR), a liquidity requirement, on the participation of banks in Term Deposit Facility (TDF) operations, a tool created by the Federal Reserve to reduce the quantity of reserves in order to control interest rates.[1] Because banks' reserves in excess of their mandatory reserve requirements help them meet the LCR requirement and because term deposits awarded in TDF operations are deducted from banks' reserve accounts for the life of the term deposits, the LCR could determine whether banks participate in TDF operations, that is, whether banks submit tenders for term deposits.[2]

Estimating causal effects of the LCR on TDF participation is challenging because unobservable characteristics of banks may determine both their LCR requirements and whether they decide to offer tenders. Thus, banks' LCR requirements and their decisions to participate in TDF operations are possibly endogenous, which can bias estimates of the effects of the LCR on TDF participation. This potential bias implies that we need an empirical strategy to break this endogeneity and identify

[1]The Federal Reserve may also use the overnight reverse repurchase program (ON RRP) and term RRP to reduce reserves. Alternatively, reserves can be reduced by selling securities in the System Open Market Account (SOMA) portfolio. More information about the Federal Reserve's normalization principles and plans can be found on the Board of Governors' website `www.federalreserve.gov/monetarypolicy/policy-normalization.htm`.

[2]Excess reserves account for a large share of the liquid assets held by banks subject to the LCR. By the beginning of 2014, domestic LCR banking organizations had acquired $850 billion of excess reserves, which were about 35 percent of the liquid assets used by those banks to meet the LCR requirement. Foreign depository institutions hold approximately half of the excess reserves in the system.

these effects.

Our identification strategy relies on characteristics of the LCR and of the TDF operations. In the United States, the LCR takes two forms: standard and modified. The standard LCR applies to all banking organizations with $250 billion or more in total consolidated assets or $10 billion or more in on-balance-sheet foreign exposures and to these banking organizations' subsidiary depository institutions with consolidated assets of $10 billion or more. The modified LCR, a less-stringent version of the LCR, applies to bank holding companies and savings and loan holding companies that do not meet the standard thresholds but have $50 billion or more in consolidated assets. Based on the modified LCR asset threshold, very similar banks may or may not be subject to the LCR, which generates exogenous variation in LCR requirements that we can use to estimate the effects of the LCR on TDF participation. Moreover, neither the standard nor modified U.S. LCR requirements apply to U.S. branches and agencies of foreign banks, providing us with another comparison group. In addition, the characteristics of the TDF changed over time. Although early operations did not allow banks to withdraw funds prior to maturity, all operations from October 2014 to the present include an early withdrawal feature (EWF). An EWF allows term deposits to count toward the LCR, thereby increasing the incentives for banks subject to the LCR in the United States (LCR banks, for conciseness) to participate in TDF operations. This change over time helps to separate the effects of the LCR from the effects of other policies that are also triggered by the $50 billion asset threshold.[3]

More specifically, we compare changes in TDF participation rates of standard and modified LCR banks before and after an EWF was introduced with the same changes for banks not subject to the LCR (non-LCR banks).[4] We also compare changes between LCR banks and large U.S. branches and agencies of foreign banks (large foreign banks), which are not covered by the U.S. version of the LCR. We distinguish between large and small foreign banks using a $50 billion asset threshold, which is equal to the modified LCR threshold.

We estimate that the odds that an LCR bank participates in an operation increases between

[3]For example, banking organizations above the $50 billion threshold must also participate in the annual stress tests and get approval on their capital plans.

[4]The fact that the U.S. LCR rule uses a $50 billion threshold to determine which banks are subject to the standard or the modified LCR suggests that a regression discontinuity research design may be appropriate to address the question that we study. However, because of the small number of banks with assets close to this threshold, we consider the empirical strategy described in Section 4 more appropriate. Still, a regression discontinuity research design generates results similar to those presented in this paper.

2.3 and 7.1 percentage points relative to a non-LCR bank per operation after an EWF is added. These odds imply that by the fifth operation with an EWF, the difference between participation rates of LCR and non-LCR banks increases between 11.5 and 35.5 percentage points. We also find evidence that an EWF increases the tender amounts of LCR banks compared to non-LCR banks. These estimates confirm the material changes in the dollar amounts awarded and the participation rates after an EWF was introduced. For example, although the June 9 and October 20, 2014, TDF operations had similar characteristics, the October operation, which offered an EWF, awarded a much larger amount and had stronger participation.[5] In fact, between the two operations, the aggregate size more than doubled, from $78 billion to $172 billion, while the number of participants increased by more than half, from 40 to 66. Our finding that LCR banks participate more often and submit larger tenders with the introduction of an EWF is robust to several changes to the specifications, including narrowing the window around the LCR asset threshold and narrowing or expanding the sample used based on bank characteristics that may affect participation.

This paper contributes to the nascent literature on liquidity regulation. Allen (2014) and Diamond and Kashyap (2015) survey this literature and argue that more research is needed to answer fundamental questions on liquidity regulation. In particular, Diamond and Kashyap (2015) note that "in implementing the new liquidity regulations it seems fair to say we are in a situation where practice is far ahead of both theory and measurement." We contribute to this literature by estimating the effects of a new liquidity regulation on bank demand in monetary policy operations.

As far as we know, Bonner and Eijffinger (2013) and Banerjee and Mio (2015) have conducted the only empirical studies about the impact of the LCR so far. Bonner and Eijffinger (2013) investigate the effects of non-compliance with a liquidity requirement similar to the LCR by Dutch banks on their borrowing and lending terms and volumes. Banerjee and Mio (2015) use the variation over time and across banks in the implementation of a liquidity requirement also similar to the LCR to study the impact of liquidity regulation on bank balance sheets and bank lending in the United Kingdom. The empirical strategies of these papers, however, differ significantly from ours because we exploit characteristics that are specific to the TDF and the U.S. LCR rule to identify the impact of the LCR on bank behavior. In addition, these papers study the effects of the LCR

[5]The two operations did not overlap with other operations, had the same caps on tender amounts ($10 billion), and offered term deposits with the same interest rate (26 basis points) and the same maturity (7 days).

on bank balance sheets and bank behavior in the interbank money market and in private sector lending, whereas we investigate effects on bank demand in monetary policy operations.

Our paper is related to theoretical work on the impact of the LCR through banks on the effectiveness of monetary policy, which includes Bech and Keister (2015) and Duffie and Krishnamurthy (2016). Bech and Keister (2015) present a model of monetary policy implementation with term funding and a liquidity requirement similar to the LCR. Their study shows that the LCR may change bank demand for central bank reserves, thereby also changing the effects of monetary policy operations on equilibrium interest rates. We contribute to their work showing empirical evidence that confirms that the LCR affects bank demand for central bank reserves. Indeed, because term deposits awarded in TDF operations are deducted from banks' reserve accounts at the Federal Reserve, our finding that the LCR affects bank demand for term deposits implies that the LCR affects bank demand for reserves.

Duffie and Krishnamurthy (2016) build a model to examine how the LCR may attenuate the pass-through effectiveness of monetary policy by the Federal Reserve. When the LCR is binding, banks reduce their demand for assets that count the least towards the LCR compared with their demand for assets that count the most. This shift in demand distorts the spread between the rate of return on those assets, thereby reducing the pass-through effectiveness of monetary policy. We contribute to their work by providing empirical evidence that the LCR affects the demand for assets that do not count towards the LCR (term deposits without an EWF) relative to assets that count (term deposits with an EWF). In addition, our results show that an EWF attenuates the impact of the LCR on bank demand for term deposits, confirming the findings from Bech and Keister (2015) and Duffie and Krishnamurthy (2016) that central banks can adjust their monetary policy tools to accommodate the LCR.

Our paper is also related to research that analyzes other effects of liquidity regulation. Adrian and Boyarchenko (2013) and Covas and Driscoll (2014) develop dynamic general equilibrium models to study the interactions between a liquidity requirement and a capital requirement for the banking sector and the effects of those requirements on consumption and bank risk. Diamond and Kashyap (2015) investigate the effects of liquidity regulation on bank runs. Walther (2016) examines the effects of a liquidity regulation similar to the net stable funding ratio and capital requirements on systemic risk. We contribute to these papers with empirical evidence that liquidity regulation

affects bank behavior materially, which is an important feature of their models.[6]

Moreover, our paper contributes to the recent literature on monetary policy implementation in an environment where banks hold large amounts of excess reserves (Bech and Klee, 2011; Kashyap and Stein, 2012; Martin, McAndrews, Palida, and Skeie, 2013; Chen, Clouse, Ihrig, and Klee, 2014; Ennis, 2014; Armenter and Lester, 2015; Ihrig, Meade, and Weinbach, 2015; Williamson, 2015; Kandrac and Schlusche, 2016). As far as we know, the only papers in this literature with empirical analysis are Bech and Klee (2011) and Kandrac and Schlusche (2016). However, their topics are different from ours: Bech and Klee (2011) study the determinants of bargaining power in the federal funds market, and Kandrac and Schlusche (2016) analyze the effects of excess reserves on bank lending and risk taking. In contrast, we investigate the relation between liquidity regulation and participation in TDF operations.

To our best knowledge, the only papers in this literature that study the TDF are Martin, McAndrews, Palida, and Skeie (2013); Chen, Clouse, Ihrig, and Klee (2014); and Ihrig, Meade, and Weinbach (2015). Martin, McAndrews, Palida, and Skeie (2013) use a theoretical model to investigate in what situations it would be optimal to use new monetary policy tools, including the TDF, to control interest rates. Chen, Clouse, Ihrig, and Klee (2014) present a theoretical model to evaluate whether these tools would allow the Federal Reserve to raise short-term interest rates in an environment with abundant excess reserves. Ihrig, Meade, and Weinbach (2015) describe how these tools may be used for monetary policy implementation. Our paper differs from these three papers because we study the TDF empirically. We contribute to this literature by showing empirical evidence that liquidity requirements affect bank demand in monetary policy operations.

The rest of this paper is organized as follows: Section 2 presents some background on the TDF and the LCR, Section 3 summarizes our data, Section 4 describes our empirical strategy, Section 5 presents our results, and Section 6 concludes.

[6]More generally, our paper contributes to recent work on bank regulation and monetary policy implementation through banks. Bianchi and Bigio (2014) study how capital requirements, shocks to the banking system, and monetary policy alter the tradeoff between profiting from lending and increasing liquidity risk. However, they analyze the effects of capital regulation, whereas we study the effects of liquidity regulation. Still, our empirical results confirm that bank regulation affects bank demand in monetary policy operations, which is an important result of their paper.

2 Background on the TDF and the LCR

2.1 TDF

The TDF is a tool created by the Federal Reserve to manage the aggregate quantity of reserves held by depository institutions.[7] Only depository institutions eligible to receive interest from the Federal Reserve are allowed access to term deposits through the TDF.[8] The funds placed in a term deposit are deducted from the institution's reserve account for the life of the deposit, effectively draining those reserves from the banking system and putting upward pressure on interest rates. From the institutions' perspective, term deposits are an alternative to excess reserves as an asset that can be held with the central bank, with the advantage that term deposits pay a slightly higher interest rate.

Although operations have so far been mostly intended to ensure the operational readiness and to give institutions familiarity with the functionality, the TDF could be an important tool in the future. For instance, the Federal Open Market Committee (FOMC) indicated plans to use supplementary tools, such as the TDF, as needed to control the federal funds rate during the process of monetary policy normalization (Federal Open Market Committee, 2014).[9]

The Federal Reserve determines the characteristics of the operations confidentially and announces them prior to the operation dates. As part of TDF testing, the Federal Reserve has changed many characteristics of the term deposits over successive operations. Characteristics that have varied include operation format (offering a fixed or floating interest rate), maturity, interest rate, maximum deposit amount, and the time between the operation and its settlement. Table 1 shows the main changes in the characteristics of the 16 operations held between May and December of 2014, which we study in this paper.[10] The offered rates and the maximum tender amounts

[7] The Federal Reserve started offering TDF operations in 2010. Operation details are available on the Board of Governors' website under Monetary Policy and Policy Tools (`www.federalreserve.gov/monetarypolicy/tdf.htm`).

[8] An institution can participate in TDF operations if it is eligible to receive interest from the Federal Reserve and if it has a location to settle funds from TDF transactions. Interest eligibility is defined by Regulation D. Institutions eligible to receive interest from the Federal Reserve include commercial banks, thrifts, and credit unions. To submit a tender, the institution must also have a means of accessing the TDF application.

[9] Federal Open Market Committee (2014) defines monetary policy normalization as the steps to raise the federal funds rate and other short-term interest rates to more normal levels and to reduce the Federal Reserve's securities holdings.

[10] We focus on these 16 operations because, with the exception of their EWF status, they had very similar characteristics. Operations conducted before and after this time period differ substantially from these 16 operations. For example, operations conducted before May 2014 had much lower maximum tender amounts, and the first three

Table 1: TDF Operation Details

EWF	Operation date	Rate (basis points)	Maximum tender amount ($ billions)
No	May 19	26	3
No	May 27	26	5
No	June 2	26	7
No	June 9	26	10
No	June 16	27	10
No	June 23	28	10
No	June 30	29	10
No	July 7	30	10
Yes	October 14	26	5
Yes	October 20	26	10
Yes	October 27	26	15
Yes	November 3	26	20
Yes	November 10	27	20
Yes	November 17	28	20
Yes	November 24	29	20
Yes	December 1	30	20

Note: This table shows summary statistics of all 16 TDF operations conducted from May to December 2014. All operations offered seven-day term deposits with fixed interest rates, full-allotment tenders, and a minimum tender amount of $10,000.

increase between May and July, drop between July and October, and increase again between October and December. In addition, operations before July do not allow institutions to withdraw funds prior to maturity, and all operations from October to present include an EWF subject to a pecuniary penalty, which consists of the forfeiture of all interest and an annual penalty rate of 0.75 percent applied to the principal amount.

However, some important characteristics remained unchanged throughout this period: All these operations offered fixed interest rates and a minimum tender amount of $10,000. Also, all these operations followed a full-allotment policy, that is, the amount of term deposits for each bank was limited only by the maximum tender amount. Moreover, all these operations offered seven-day term deposits, except for two operations, which offered six-day (November 17) and eight-day (November 24) term deposits to account for a federal holiday.

operations that followed the December 2014 operation had overlapping maturities.

2.2 LCR

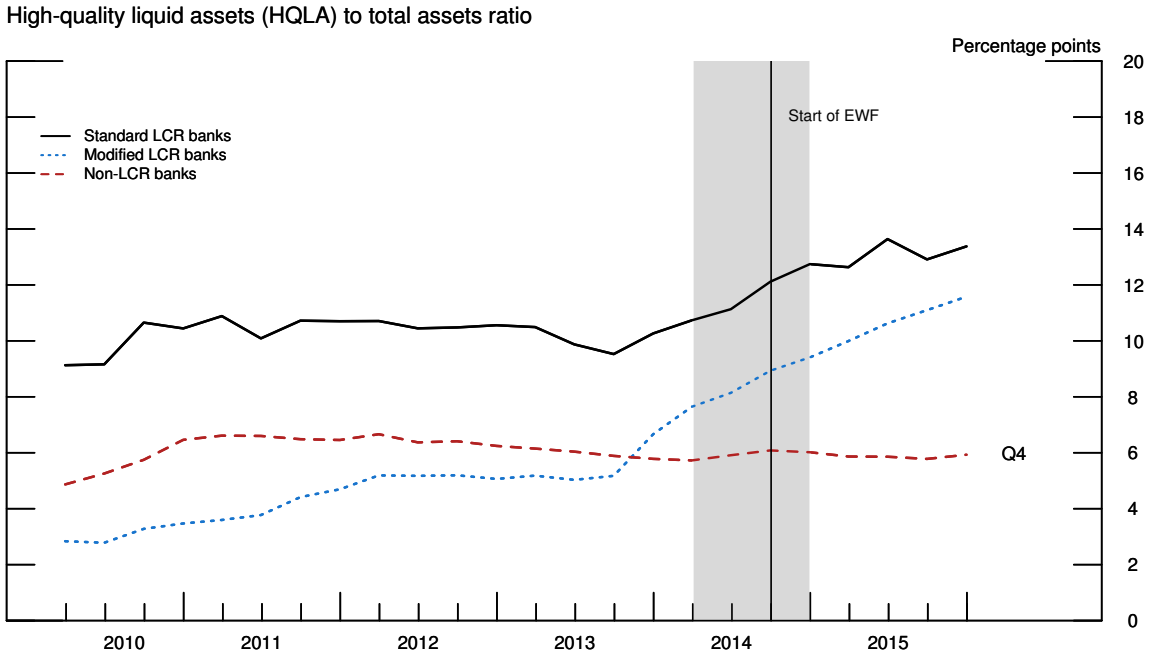
The LCR is the ratio between a bank's high-quality liquid assets (HQLA) and its projected net cash outflow over a 30-day stress scenario. As implied by the name, assets that qualify as HQLA must be easily and immediately convertible to cash with little to no loss of value. Banks subject to the LCR requirement must meet a minimum LCR ratio. Thus, the LCR promotes short-term resilience in the financial system by requiring banks to hold HQLA sufficient to cover a short-term liquidity stress scenario.[11]

The LCR applies to large and internationally active banking organizations and will be gradually implemented between 2015 and 2017. The standard LCR applies to all banking organizations with $250 billion or more in total consolidated assets or $10 billion or more in on-balance-sheet foreign exposures and to these banking organizations' subsidiary depository institutions with consolidated assets of $10 billion or more. The modified LCR, a less-stringent version of the LCR, applies to bank holding companies and savings and loan holding companies that do not meet these thresholds but have $50 billion or more in consolidated assets. Banks subject to the standard version must have an LCR of at least 80, 90, and 100 percent by January 2015, 2016, and 2017, respectively, while banks subject to the modified version must have an LCR of at least 90 and 100 percent by January 2016 and 2017, respectively. Thus, in 2014, when the TDF operations we study were conducted, the LCR did not apply.

However, as figure 1 shows, LCR banks were steadily increasing their holdings of HQLA throughout 2014. This figure shows quarterly data on the HQLA-to-total assets ratio for each of the LCR groups from the first quarter of 2010 through the fourth quarter of 2015. The HQLA ratio began to increase in late 2013 at banks subject to the LCR (either standard or modified), but remained about flat over time at banks not subject to the LCR. These changes in the HQLA ratio indicate that LCR banks were already accumulating HQLA in response to the LCR requirement before those banks were actually required to meet the LCR. This evidence has an important implication for the empirical strategy of this paper because, if in 2014 banks were already accumulating HQLA to meet the LCR, then we can interpret differences in how LCR and non-LCR banks respond to the EWF as consequences of the LCR.

[11] Basel Committee on Banking Supervision (2008, 2013) contain the Basel III background and guidelines for the LCR. The final U.S. rules are available in Federal Register (2014).

Figure 1: Ratio of HQLA to Total Assets over Time



NOTE: This figure shows quarterly data on the ratio between the estimate of HQLA described in Appendix A and total assets for each of the LCR groups from the first quarter of 2010 through the fourth quarter of 2015. The shaded areas indicate the period in which the TDF operations studied in this paper occurred, between the second and the fourth quarter of 2014. The HQLA ratio began to increase in late 2013 at banks subject to the LCR (either standard or modified), but remained about flat over time at banks not subject to the LCR. These changes over time in the HQLA ratio support our assumption that LCR banks were already accumulating HQLA in response to the LCR requirement before those banks were actually required to meet the LCR. Source: Call Report (FFIEC 031 and FFIEC 041), the Report of Transaction Accounts, Vault Cash and Other Deposits (FR 2900), and balance data from internal Federal Reserve accounting records.

In addition, figure 1 shows that, during the period that we analyze in this paper, HQLA ratios at LCR and non-LCR banks followed different trends, but those trends were apparently stable during this period. In particular, those trends did not change when an EWF was introduced in the TDF. These facts suggest that bank characteristics that might be related to TDF participation did not change simultaneously with the introduction of an EWF. In this case, changes in bank participation before and after the introduction of an EWF could be attributed to an effect of an EWF.

2.3 Relationship between the LCR and an EWF

The LCR should affect how banks respond to an EWF. In TDF operations, banks exchange excess reserves, which belong to the highest HQLA category, for term deposits, which do not qualify as HQLA if early withdrawal is not possible.[12] Thus, when a bank participates in a TDF operation without an EWF, the bank lowers its LCR. For this reason, LCR banks should submit tenders less often, and submit lower amounts, in TDF operations without an EWF than non-LCR banks with similar characteristics. For the same reason, an EWF should increase demand for term deposits among LCR banks in particular because term deposits with an EWF help these banks meet the LCR requirement.

An EWF has two characteristics that determine the empirical strategy we follow. First, even though an EWF should be particularly valuable for LCR banks, it is possible that all banks participate more often in the TDF because of an EWF. Indeed, an EWF makes term deposits more liquid, which can be valuable for any bank. Thus, our empirical strategy must account for this positive effect of an EWF on participation across all banks. In Section 4, we discuss how we address this issue.

Second, banks did not need to meet LCR requirements during the sample period. Thus, one could argue that LCR banks should not have responded to an EWF differently than non-LCR banks because none of them had to meet these liquidity requirements. Still, LCR banks should already be relatively more interested in participating in the TDF than non-LCR banks in order to gain familiarity with the TDF before term deposits became LCR-eligible. Indeed, the operations we study in this paper were intended "to ensure the operational readiness of the TDF and to provide eligible institutions with an opportunity to gain familiarity with term deposit procedures." (Board of Governors of the Federal Reserve System, 2014). Moreover, as shown in subsection 2.2, LCR banks accumulated a large amount of HQLA in 2013 and 2014, well in advance of the requirement, while non-LCR banks lowered their HQLA holdings as a share of total assets during the same period. Therefore, we assume that the LCR caused all the observed differences in how LCR and non-LCR banks responded to the EWF. Given that this assumption is fundamental to our empirical strategy, in Section 5 we investigate whether our results are robust to various changes

[12] Excess reserves and term deposits with an EWF are considered level 1 HQLA. Assets in this category are not limited as a share to a bank's total HQLA and are not discounted in LCR calculations.

in the definition of LCR banks and non-LCR banks or, equivalently, to the set of banks assigned to control and treatment groups in our empirical exercises.

3 Data

We use a panel in which each observation is a commercial bank-TDF operation pair. We include data on domestic commercial banks and U.S. branches and agencies of foreign commercial banks (foreign banks) operating in the United States. We restrict the sample to commercial banks because some of the data used in this paper are not available for other depository institutions. For domestic commercial banks, we also limit the main sample to banks that do not belong to bank holding companies and to lead banks within bank holding companies, and we define a lead bank as the largest bank by total assets within a bank holding company. By limiting the sample to one bank per domestic bank holding company, we ensure that participation decisions are independent across banks. In fact, independence across banks is particularly important in this setting because the lead banks often hold the majority of the excess reserves of their holding companies. The resulting panel is composed of the 3,687 domestic and 189 foreign commercial banks that were eligible to participate in the 16 TDF operations held between May and December 2014.[13]

Table 2 shows summary statistics of participation rates and tender amounts in TDF operations. In this table, panels 1 to 4 separate observations depending on whether they are from domestic (panels 1 and 2) or foreign (panels 3 and 4) banks. We separate observations into foreign and domestic banks because the U.S. LCR rule applies to domestic banks only. Within the domestic set, we divide data between LCR and non-LCR banks. A bank is considered an LCR bank if the bank or its bank holding company is subject to either the standard or modified LCR requirement. For foreign data, we divide the sample between large and small foreign banks using an asset threshold of $50 billion—the same threshold that the U.S. LCR rule uses to define modified LCR banks—making the panel of large foreign banks more similar to the panel of domestic LCR banks.

As shown in the four panels of table 2, participation rates and tender amounts of domestic LCR

[13]To be eligible to participate in the TDF a bank must also submit a formal application to the Federal Reserve. Thus, our sample includes banks with and without formal access to the TDF. We use the sample of banks eligible to participate in the TDF instead of the narrower sample of banks with formal access to the TDF because applying for access to the TDF is most likely a decision endogenous to unobservable bank characteristics. Still, our results are about the same if we restrict our sample to banks with formal access to the TDF.

Table 2: TDF Summary Statistics by Bank Type and Operation Type

Variable	Obs.	Banks	Mean	Std. Dev.	Min.	Max.
1. **Domestic banks, non-LCR**						
a. No EWF						
Submitted a tender (percentage points)	29,232	3,654	0.36			
Tender amount ($ millions)	29,232	3,654	0	24	0	1,400
b. With EWF						
Submitted a tender (percentage points)	29,232	3,654	0.55			
Tender amount ($ millions)	29,232	3,654	1	39	0	2,000
2. **Domestic banks, LCR**						
a. No EWF						
Submitted a tender (percentage points)	264	33	22.73			
Tender amount ($ millions)	264	33	841	2,205	0	10,000
b. With EWF						
Submitted a tender (percentage points)	264	33	39.02			
Tender amount ($ millions)	264	33	2,971	5,811	0	20,000
3. **Foreign banks, small (<$50 billion in assets)**						
a. No EWF						
Submitted a tender (percentage points)	1,361	171	4.04			
Tender amount ($ millions)	1,361	171	100	723	0	10,000
b. With EWF						
Submitted a tender (percentage points)	1,360	170	7.94			
Tender amount ($ millions)	1,360	170	270	1,622	0	20,000
4. **Foreign banks, large (≥$50 billion in assets)**						
a. No EWF						
Submitted a tender (percentage points)	151	18	32.45			
Tender amount ($ millions)	151	18	1,779	3,205	0	10,000
b. With EWF						
Submitted a tender (percentage points)	152	19	55.26			
Tender amount ($ millions)	152	19	4,825	6,862	0	20,000

Note: This table shows summary statistics of participation and tender amounts from the 16 TDF operations conducted between May and December 2014. Each observation is a bank-operation pair. The data are composed of observations from the 3,687 domestic and 189 foreign commercial banks eligible to participate in these operations.

banks and large foreign banks are higher than participation rates and tender amounts of domestic non-LCR banks and small foreign banks, respectively. Also, participation and tender amounts increase across all four groups with an EWF. For instance, as shown in panel 2, participation rates are 1.7 times larger ($39.02/22.73 = 1.7$) and tender amounts are 3.5 times larger ($2,971/841 = 3.5$) in operations with an EWF compared to operations without an EWF for LCR banks. For the most part, these are the largest proportional differences between operations with and without an EWF across all combinations of banks by ownership and size shown in table 2. Thus, these summary statistics offer some support to the hypothesis that an EWF has a stronger impact on LCR banks. However, other differences between domestic and foreign banks, LCR status, and EWF availability most likely also determine TDF participation. For this reason, in Section 4 we present an empirical

strategy intended to account for these differences and adequately identify the effects of the LCR on TDF participation.

We add data on bank characteristics to the bank-operation panel. Bank-specific data include the dollar amounts of the banks' total excess reserves in the most recent week before the respective operation.[14] For domestic banks, the data also include the total assets, return on assets, return on equity, total capital ratio, leverage ratio, net interest margin, total loan delinquency ratio, and total net charge-offs ratio from the most recent quarter before each respective operation, which are obtained from quarterly reports of condition and income (Call Reports).[15] For foreign banks, the only characteristics included in the data are total assets and excess reserves.

We also build an estimate of HQLA for domestic banks using Call Report data. Ideally, we would like to include in our data the LCR of each bank. Unfortunately, Call Reports do not include the data necessary to calculate a bank's projected net cash outflow over a 30-day stress scenario, which is the denominator of the LCR. In addition, banks do not directly report in these forms their HQLA, which is the numerator of the LCR. Thus, we build an estimate of HQLA for each bank, which we describe in Appendix A, and we use the ratio of this estimate to total assets, which we show in figure 1, in our regressions.[16]

Table 3 summarizes these data. Of note, LCR and non-LCR banks differ substantially in characteristics that should determine how banks participate in TDF operations. For example, domestic LCR banks have ratios of excess reserves to total assets and of HQLA to total assets that are more than twice as large as domestic non-LCR banks, and these differences are statistically significant.

However, figures 2 and 3 also show that bank characteristics of LCR and non-LCR banks did not change materially during the sample period. These two figures show the mean of the variables included in table 3 (except for the ratio of HQLA to total assets, which we show in figure 1) from the first quarter of 2010 to the fourth quarter of 2015. The shaded areas indicate the period in which

[14] A bank's excess reserves is for the most part equal to its average end-of-day account balances due from Federal Reserve Banks less its reserve balance requirement (RBR). Balance data are from internal Federal Reserve accounting records whereas bank-level RBR is calculated based on confidential filings of the FR 2900 Report of Transaction Accounts, Vault Cash and Other Deposits.

[15] Call Reports are mandatory forms filed quarterly by commercial banks (Consolidated Report of Condition and Income, FFIEC 031 and FFIEC 041).

[16] HQLA is estimated primarily using excess reserves and security assets with a 0 percent or a 20 percent risk weight (Call Report Schedule RC-R).

Table 3: Summary Statistics of Bank Characteristics

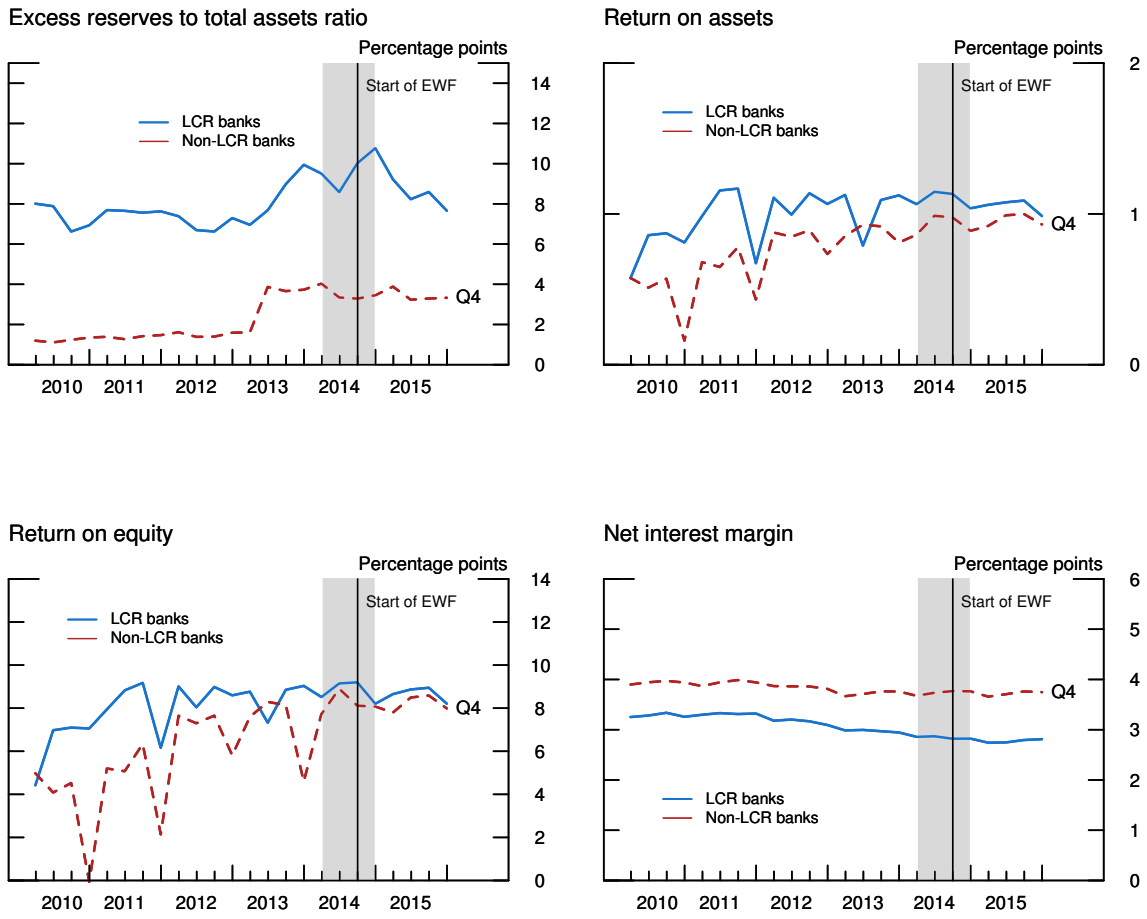
	Domestic banks		Foreign banks	
	Non-LCR	LCR	Assets less than $50 billion	Assets at least $50 billion
Total assets ($ millions)	783	310,561**	5,147	89,032**
	(2,591)	(484,280)	(8,690)	(27,420)
Return on assets	0.93	1.10*		
	(1.68)	(0.97)		
Return on equity	8.00	9.00		
	(24.63)	(5.98)		
Net interest margin	3.73	2.84**		
	(1.07)	(1.43)		
Total capital ratio	18.38	15.59**		
	(13.60)	(5.58)		
Leverage ratio	10.68	10.54		
	(4.29)	(2.92)		
Loan delinquency ratio	2.59	2.10**		
	(2.87)	(1.32)		
Net charge-off ratio	0.20	0.42**		
	(0.93)	(0.59)		
Excess reserves/total assets	3.53	9.28**	43.15	47.37
	(6.13)	(12.27)	(83.10)	(30.61)
HQLA/total assets	5.07	10.42**		
	(7.32)	(8.06)		
Observations	58,464	528	2,721	303
Banks	3,654	33	170	19

Note: The unit of observation is a bank-operation pair. The sample includes domestic commercial banks that do not belong to a bank holding company, domestic commercial banks that are the lead bank within a bank holding company, and all foreign commercial banks operating in the United States in 2014. Excess reserves are based on two-week averages of data prior to each TDF operation, covering a period from early May 2014 to late November 2014. All other data are based on quarter-end data from Call Reports for March 31, June 30, and September 30 of 2014. HQLA data are estimated from these forms because they are not directly reported. See Appendix A for more details. All variables are measured in percentage points, except when stated otherwise. * and ** indicate that a two-sided t-test rejects the hypothesis that the mean in the column is the same as the mean in the column on the left at the 5 and 1 percent levels, respectively. T-tests are done separately for domestic and foreign banks. Standard deviations are in parentheses.

the TDF operations studied in this paper occurred, between the second and the fourth quarter of 2014. Because this period is shorter than one year, bank characteristics changed little during this time interval. Moreover, trends in characteristics of LCR and non-LCR apparently did not change when an EWF was introduced.

The measures of availability of reserves and of profitability in figure 2 remained mostly stable over the sample period. The ratio of excess reserves to total assets (top left panel) remained about

Figure 2: Bank Characteristics over Time

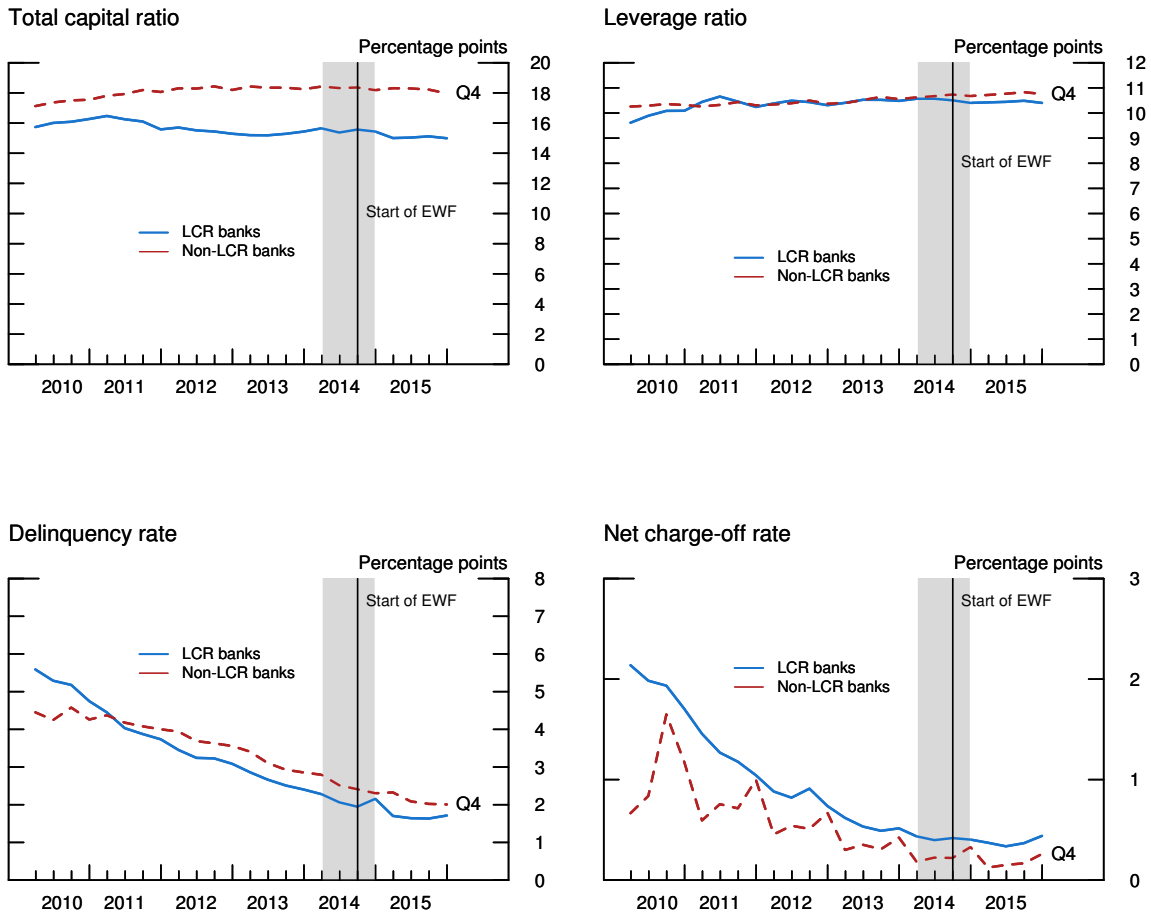


NOTE: This figure shows quarterly data on the ratio between excess reserves and total assets, return on assets, return on equity, and net interest margin for LCR and non-LCR domestic banks from the first quarter of 2010 through the fourth quarter of 2015. The shaded areas indicate the period in which the TDF operations studied in this paper occurred, between the second and the fourth quarter of 2014. Source: Call Report (FFIEC 031 and FFIEC 041), the Report of Transaction Accounts, Vault Cash and Other Deposits (FR 2900), and balance data from internal Federal Reserve accounting records.

flat for non-LCR banks, but increased for LCR banks. However, the increase in this ratio for LCR banks is about the same in the third and in the fourth quarter of 2014, that is, immediately before and after the introduction of an EWF. Return on assets (top right panel) and return on equity (bottom left panel) were similar and stable for LCR and non-LCR banks from the second to the fourth quarter of 2014. Net interest margins (bottom right panel) of LCR banks changed little throughout the period covered in this figure.

The measures of capitalization and delinquency in figure 3 also remained stable between the

Figure 3: Bank Characteristics over Time (continued)



NOTE: This figure shows quarterly data on total capital ratio ratio, leverage ratio, delinquency rate, and net charge-off rate for LCR and non-LCR domestic banks from the first quarter of 2010 through the fourth quarter of 2015. The shaded areas indicate the period in which the TDF operations studied in this paper occurred, between the second and the fourth quarter of 2014. Source: Call Report (FFIEC 031 and FFIEC 041).

second and the fourth quarter of 2014. Total capital ratios (top left panel) and leverage ratios (top right panel) were about unchanged for both LCR and non-LCR banks during the period covered in this figure. Delinquency rates (bottom left panel) and net charge-off rates were similar and stable at low levels for LCR and non-LCR banks during 2014. In summary, bank characteristics of LCR and non-LCR banks are quite similar before and after the introduction of an EWF during the sample and thus most likely did not cause any changes in participation of LCR and non-LCR banks during that period.

4 Empirical Strategy

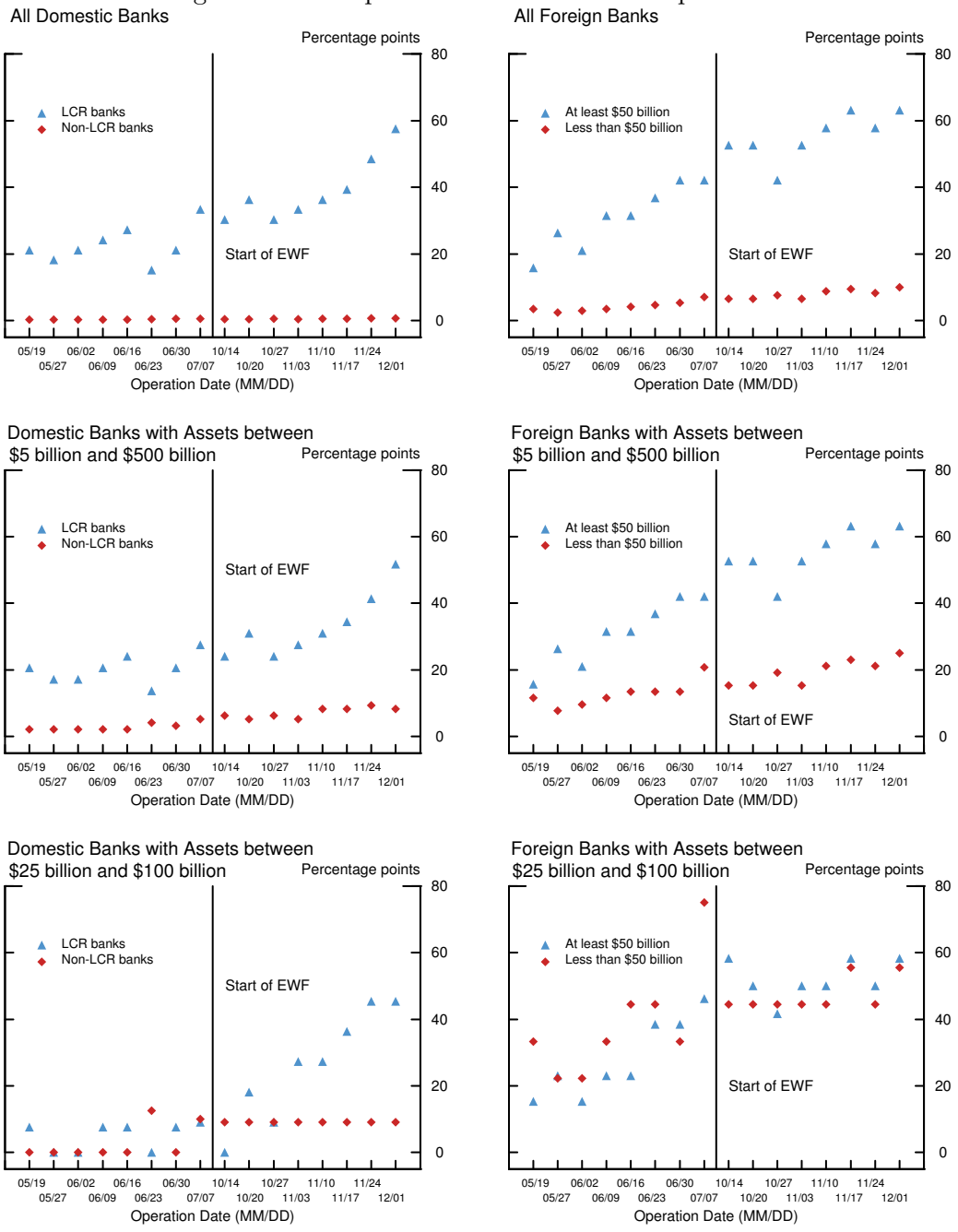
In this section, we describe the empirical strategy used to investigate whether TDF participation depends on whether a bank is subject to the LCR and whether the operation has an EWF. We mainly use an indicator of whether a bank submitted a tender in a TDF operation as the dependent variable to avoid biases in our estimates caused by the censoring of tender amounts. Indeed, tender amounts are censored from above and below because all operations have maximum tender amounts and a minimum tender amount of $10,000. In addition, caps on tender amounts vary across operations, with operations with an EWF having higher caps, on average. In fact, as shown in table 2, some banks submitted tender amounts equal to the maximum allowed. Still, we show that regressions using tender amounts and a participation indicator as the dependent variable yield similar results: tender amounts and participation rates increase with the introduction of an EWF.

Figure 4 motivates the empirical strategy. This figure shows bank participation rates over the 16 TDF operations held between May and December 2014. The panels on the left show domestic banks, and the panels on the right show foreign banks. The top panels include data from all banks, while the middle and bottom panels restrict the sample based on bank asset size, narrowing the sample to banks within an interval of assets around the $50 billion threshold. In each panel, a vertical line indicates when an EWF was introduced.

Note that as this interval of assets narrows for domestic banks (moving from the top left to the bottom left panel), participation rates of LCR banks and non-LCR banks get closer in the pre-EWF period, the operations to the left of the vertical line. In fact, participation rates of domestic LCR and non-LCR banks between $25 billion and $100 billion are very similar and are about flat in operations without an EWF. Thus, these panels suggest that non-LCR domestic banks become a better comparison group to estimate the effects of an EWF on LCR domestic banks as we narrow the interval of bank assets.

Also of note, participation rates of LCR banks trend upward, while rates of non-LCR banks remain flat after an EWF is introduced. Thus, LCR banks apparently respond differently to an EWF in a direction consistent with the hypothesis that an EWF increases the value of term deposits for LCR banks more than it does for non-LCR banks. The EWF may have caused a gradual increase in participation of LCR banks compared to non-LCR banks instead of an immediate jump, for

Figure 4: Participation of Banks in TDF Operations



NOTE: This figure shows bank participation rates over the 16 TDF operations held between May and December 2014. The panels on the left show domestic banks, and the panels on the right show foreign banks. The top panels include data from all banks, while the middle and bottom panels restrict the datal based on bank asset size. In each panel, a vertical line indicates when an EWF was introduced. Also, domestic banks are divided between those affiliated with banking organizations subject to the LCR (standard or modified) and those affiliated with organizations that are exempt from the LCR. Participation rates for foreign banks are divided between those with less than $50 billion and those with at least $50 billion in total assets.

example, because banks must apply for access to the TDF and the Federal Reserve must approve their access before banks can participate in the TDF. This application process may have caused a delay for some banks between the date in which they decided to participate in the TDF and the operation in which they actually participated for the first time. In addition, as shown in table 1, the later operations had higher spreads and larger maximum tender amounts, making them more attractive. These differences in participation trends motivate our main empirical strategy in which we estimate whether an EWF caused an increase in the participation trend of domestic LCR banks using domestic non-LCR banks as a control group. Based on this strategy, we interpret estimates of a positive change in that trend as evidence of the LCR's effect on TDF participation.

The panels on the right of figure 4 show participation rates of foreign banks. Participation rates of all foreign banks and foreign banks with assets between $5 billion and $500 billion, shown in the top right and the middle right panels, are very similar to rates of domestic banks, shown in the top left and the middle left panels. Participation rates of foreign banks increase over time and this trend is stronger for larger banks. However, as we narrow the sample to banks with assets between $25 billion and $100 billion, participation rates of foreign banks, shown in the bottom right panel, differ substantially from the rates of domestic banks, shown in the bottom left panel. Rates of foreign banks above and below the $50 billion threshold are, on average, very similar with and without an EWF, while rates of domestic banks subject to and exempt from LCR are also similar without an EWF but have very different trends once an EWF is introduced.

These facts are consistent with the hypothesis that an EWF does not increase the value of term deposits for large foreign banks more than it does for small foreign banks because none of them are subject to the U.S. LCR rule. However, several of these foreign banks are subject to an LCR requirement of their home country. In fact, several of the foreign banks that participated in TDF operations publicly disclose a ratio. Given that these disclosed ratios are generally well above 100 percent, the requirement was likely less binding, which explains the growing participation of foreign banks across all operations. Of note, foreign banks held about half of the excess reserves in the system at this time, and if LCR rules are not binding, the slightly higher rate of return on TDF operations over excess reserves was likely enough to motivate participation. Overall, these facts motivate an alternative empirical strategy in which we estimate whether an EWF caused an increase in the participation trend of domestic LCR banks using foreign banks with at least $50

billion as a control group.

5 Results

5.1 Participation of Domestic LCR Banks and Domestic Non-LCR Banks

We begin exploring the effects of an EWF by testing participation rates of domestic banks. We use an empirical strategy adapted from a differences-in-differences strategy. A differences-in-differences strategy would typically investigate whether an EWF causes an immediate change in TDF participation, but we investigate whether an EWF causes a gradual change in participation as motivated by figure 4. Because of this evidence, we believe that measuring a change in the trend of participation over time is more suitable than measuring an immediate change in participation. We estimate the following equation:

$$Y_{ij} = \alpha LCRBank_i + \beta LCRBank_i \times t + \gamma LCRBank_i \times t \times EWF_j + \nu_i + \varphi_j + \varepsilon_{ij}, \quad (1)$$

where Y_{ij} is a dummy variable equal to 1 if bank i submitted a tender in operation j and equal to 0 otherwise. $LCRBank_i$ is a dummy variable equal to one if bank i's holding company has the characteristics that will make it subject to either the standard or modified LCR requirement and zero otherwise.[17] EWF_j is the indicator of whether operation j has an EWF, and t is an operation trend normalized to one in the first operation with an EWF.[18] ν_i is a bank random effect, φ_j is an operation fixed effect, and ε_{ij} is a bank- and operation-specific unobservable error. ν_i and ε_{ij} have independent normal distributions with a mean of zero and variance of σ_ν^2 and σ_ε^2. Note that this specification is analogous to a differences-in-differences model using ΔY_{ij} as the dependent variable. The interaction term $\gamma LCRBank_i \times t \times EWF_j$ measures the change in the trend of participation rates of LCR banks relative to non-LCR banks after the introduction of an EWF. Thus, γ estimates the difference between the effects of an EWF on the participation of LCR and non-LCR banks.

In Appendix B, we use a simple model to show that, under additional assumptions, the parameter estimated by the differences-in-differences between participation of LCR and non-LCR banks

[17] The list of banks that met the criteria to be subject to the LCR did not change during the sample period. As a result, the LCR status is fixed at the bank level throughout the sample period and the variable $LCRBank_i$ does not need a subscript j.

[18] The EWF was introduced in the ninth operation in our sample and thus $t \in \{-7, -6, ..., 7, 8\}$.

Table 4: TDF Participation of Domestic Banks

	(1) All banks	(2) Banks with assets between $5 billion & $500 billion	(3) Banks with assets between $25 billion & $100 billion
LCRBank	0.186**	0.174*	0.123
	(0.071)	(0.076)	(0.082)
LCRBank × t	0.008	-0.001	-0.021
	(0.006)	(0.007)	(0.019)
LCRBank × t × EWF	0.023*	0.024*	0.071**
	(0.010)	(0.012)	(0.027)
Observations	58,992	1,994	344
Banks	3,687	126	24
R-squared	0.13	0.12	0.15

Note: This table shows estimates of equation (1). The dependent variable is a dummy variable equal to 1 if bank i submits a tender in operation j and equal to 0 otherwise. $LCRBank_i$ is a dummy variable equal to one if the bank's holding company i is subject to either the standard or modified LCR requirement and zero otherwise. EWF_j is the indicator of whether operation j has an EWF, and t is an operation trend normalized to one in the first operation with an EWF. All equations include operation fixed effects. Standard errors are clustered at the bank level and are shown in parentheses. * and ** denote significant at the 5 and 1 percent levels, respectively.

in operations with and without an EWF can be interpreted as the shadow cost of the LCR. The shadow cost of the LCR could be an important measure for monetary policy implementation. For example, Duffie and Krishnamurthy (2016) show that this cost can inhibit the creation of short-term bank liabilities, thereby reducing the pass-through effectiveness of monetary policy.

Table 4 shows the regression results using equation (1). Columns 1 to 3 use the same subsamples from the top left, middle left, and bottom left panels in figure 4, respectively. Column 1 shows the results using data from all banks. The estimate of γ in this column is positive and statistically significant, with a value of 0.023. This result suggests that the probability that an LCR bank participated in a TDF operation relative to a non-LCR bank increased from 2.3 percent to 18.4 percent over the course of the eight EWF operations ($2.3 \times 8 = 18.4$). Also, the coefficient on the LCR dummy is positive, which is expected based on the summary statistics that show that LCR banks generally have higher participation rates (table 2 and figure 4).

The estimate of γ in column 1 of table 4 suggests that an EWF causes an increase in the participation of LCR banks relative to non-LCR banks, but it may also be driven by differences

in characteristics of LCR and non-LCR banks that are unrelated to the LCR. Indeed, LCR banks are much larger and complex than non-LCR banks on average, which may explain why LCR banks respond differently to an EWF. Thus, to compare observations from banks with more similar characteristics, columns 2 and 3 narrow the sample to observations from banks with assets close to $50 billion. As we move from column 1, all banks, to column 3, banks with assets between $25 billion and $100 billion, the estimate of γ increases and remains statistically significant, despite the sharp drop in the number of observations. The fact that γ increases as we narrow our sample supports the hypothesis that the stronger effect of an EWF on LCR banks is caused by the LCR, not by differences between unobservable characteristics of LCR and non-LCR banks.

5.2 Tender Amounts of Domestic LCR Banks and Domestic Non-LCR Banks

We next test whether bank tender amounts were affected by an EWF. To do this, we estimate a bidding model as follows:

$$\begin{aligned} B_{ij} &= C_j, \ if \ C_j < Y_{ij} \\ &= Y_{ij}, \ if \ R_j \leq Y_{ij} \leq C_j \\ &= 0, \ if \ Y_{ij} < R_j, \end{aligned} \tag{2}$$

where B_{ij} is the tender amount submitted by bank i in operation j, and R_j and C_j are the minimum and the maximum tender amounts of this operation. Y_{ij} is still determined by equation (1), but Y_{ij} is now the latent value of bank i's tender amount in operation j. All these variables enter equation (2) as the natural logarithm of the respective variable measured in thousands of U.S. dollars.

Table 5 presents these results using the subsamples of banks with assets above $1 billion, between $5 billion and $500 billion, and between $25 billion and $100 billion in columns 1 to 3, respectively.[19] The estimates of γ increase as we narrow the interval of assets, moving from column 1 to 3, and become statistically significant when we restrict the sample to banks with assets between $25 billion and $100 billion in column 3. This result supports our hypothesis that LCR banks submit larger

[19]Column 1 of table 5 restricts the sample to observations from banks with assets above $1 billion because of difficulties in the computation of the tobit model described by equation (2). Ideally, this column should use observations from all banks, as column 1 of table 4 does. However, possibly because of the large fraction of banks with assets below $1 billion that do not participate in TDF operations, estimates of the tobit model with this broader sample could not be computed.

Table 5: TDF Tender Amounts of Domestic Banks

	(1) Banks with assets above $1 billion	(2) Banks with assets between $5 billion & $500 billion	(3) Banks with assets between $25 billion & $100 billion
LCRBank	27.445**	28.490**	50.033*
	(3.796)	(5.422)	(20.512)
LCRBank × t	0.012	-0.870	-5.782*
	(0.356)	(0.444)	(2.596)
LCRBank × t × EWF	0.804	1.126	8.205**
	(0.549)	(0.675)	(3.138)
Observations	7,690	1,994	344
Banks	492	126	24
Log-likelihood	-1,163	-764	-164

Note: This table shows estimates of the model composed of equations (1) and (2). The dependent variable is the natural logarithm of bank i's tender amount in operation j measured in thousands of U.S. dollars. $LCRBank_i$ is a dummy variable equal to one if the bank's holding company i is subject to either the standard or modified LCR requirement and zero otherwise. EWF_j is the indicator of whether operation j has an EWF, and t is an operation trend normalized to one in the first operation with an EWF. All equations include operation fixed effects. Standard errors are clustered at the bank level and are shown in parentheses. * and ** denote significance at the 5 and 1 percent levels, respectively.

bids than non-LCR banks in operations with an EWF.

To gauge the impact on tender amounts implied by the estimate of γ in column 3, we perform a simple exercise as follows. Assume that, in the absence of the EWF, an LCR bank would submit a tender equal to the minimum amount, equal to $10,000. If an EWF were included in that operation for the first time, the same bank would submit a tender equal to $37 million. Although this increase of more than 1,000 times in the tender amount may appear to be too large, we note that, as shown in table 2, the average positive tender amount by LCR banks in operations with an EWF is about $3 billion.

The results using dollar amounts from tenders as the dependent variable complement the results using a participation indicator, giving further support to the hypothesis that an EWF has a stronger impact on the demand of TDF deposits by LCR banks relative to non-LCR banks. However, in our view the econometric evidence using a participation indicator is preferable to the evidence using tender amounts in the setting that we study for two main reasons. First, the linear probability model that we use with the participation indicator allows us to interpret directly the effect implied

by the coefficient estimates, which is not possible with the nonlinear model that we use with tender amounts. Second, estimates of the nonlinear model that we use, a tobit, are typically less robust in settings such as the one that we study, in which most observations are left-censored (banks do not submit tenders) and in which we must estimate the coefficients of independent binary variables (such as γ). For these reasons, we adopt the specifications using the participation indicator, instead of the tender amounts, as our benchmark.

Although the results using dollar amounts from tenders as the dependent variable corroborate the results using a participation indicator, we recognize that all these results may still be driven by unobservable characteristics of LCR and non-LCR banks that determine how they respond to an EWF. In fact, even when we restrict our sample to banks within the interval from $25 billion to $100 billion, LCR banks remain much larger than non-LCR banks, on average. Narrowing this interval much further is not possible because the number of banks in it, 24, is already quite small. For this reason, we next compare the participation of banks of more similar sizes—and, possibly, similar unobservable characteristics—that are subject to and not subject to the U.S. LCR. In the next subsection, we compare participation rates of large domestic banks and large foreign banks.

5.3 Participation of Large Domestic and Large Foreign Banks

We next show evidence of the effects of an EWF on participation rates using the domestic LCR banks as a treatment group and foreign banks with at least $50 billion in assets, which are non-LCR banks, as a control group. For clarity, the $LCRBank$ notation is replaced with DOM, making the specification

$$Y_{ij} = \alpha DOM_i + \beta DOM_i \times t + \gamma DOM_i \times t \times EWF_j + \nu_i + \varphi_j + \varepsilon_{ij}, \quad (3)$$

where Y_{ij}, EWF_j, ν_i, φ_j, and ε_{ij} are defined as before, and DOM_i is a dummy variable equal to one for domestic banks and equal to zero for foreign banks. Once again, γ measures the difference in the impact of an EWF on the trend of TDF participation between LCR and non-LCR banks.

Table 6 shows the results. Columns 1 to 3 use observations from banks with at least $50 billion. The coefficient of interest is the interaction term $DOM_i \times t \times EWF_j$. The estimated coefficient increases and becomes statistically significant as we narrow the sample from banks with at least

Table 6: TDF Participation of Large Domestic and Large Foreign Banks

	Large Banks			Small Banks		
	(1)	(2)	(3)	(4)	(5)	(6)
	Banks with assets above $50 billion	Banks with assets between $50 billion & $500 billion	Banks with assets between $50 billion & $100 billion	Banks with assets below $50 billion	Banks with assets between $5 billion & $50 billion	Banks with assets between $25 billion & $50 billion
DOM	-0.045	-0.054	-0.138	-0.015	-0.044	-0.192
	(0.129)	(0.130)	(0.146)	(0.013)	(0.043)	(0.166)
DOM × t	-0.023	-0.028*	-0.038*	-0.006*	-0.008	-0.032
	(0.014)	(0.014)	(0.019)	(0.002)	(0.006)	(0.032)
DOM × t × EWF	0.031	0.034	0.082**	0.002	0.005	0.041
	(0.019)	(0.020)	(0.030)	(0.003)	(0.009)	(0.039)
Observations	799	735	373	61,217	2,391	314
Banks	51	47	26	3,827	155	23
R-squared	0.08	0.09	0.17	0.02	0.04	0.24

Note: This table shows estimates of equation (3). The dependent variable is a dummy variable equal to 1 if bank i submitted a tender in operation j and equal to 0 otherwise. DOM_i is a dummy variable equal to one for domestic banks and equal to zero for foreign banks. EWF_j is the indicator of whether operation j has an EWF, and t is an operation trend normalized to one in the first operation with an EWF. All equations include operation fixed effects. Standard errors are clustered at the bank level and are shown in parentheses. * and ** denote significant at the 5 and 1 percent levels, respectively.

$50 billion in assets in column 1 to banks between $50 billion and $100 billion in column 3. This increase in γ is consistent with the graphical evidence from figure 4 and the hypothesis that an EWF increases participation of LCR banks more than it does for non-LCR banks.

Columns 4 to 6 provide additional support to this hypothesis based on a falsification test. In these columns, we restrict the sample to domestic and foreign banks with less than $50 billion in assets, which are all non-LCR banks. Thus, if the hypothesis that an EWF affects participation of LCR and non-LCR banks differently because of the LCR is correct, γ should not be significant in any of these columns. Indeed, γ is never significant, even when we narrow the sample to observations from banks between $25 billion and $50 billion in total assets in column 6.

Restricting the panel to domestic and foreign banks above or below the $50 billion threshold cannot fully eliminate the possibility that our results are driven by unobservable characteristics of domestic and foreign banks that determine how they respond to an EWF. For example, foreign banks typically hold more assets abroad than domestic banks and these assets, which we cannot observe, may cause differences in the willingness of foreign and domestic banks to participate in

the TDF. This limitation is similar to the one we discussed in the comparison between larger and smaller domestic banks in the previous subsection. Thus, in the next subsections we provide additional evidence that the stronger impact of an EWF on LCR banks is caused by the LCR and not by differences in unobservable characteristics.

5.4 Robustness Results

In this subsection, we test the robustness of our baseline results shown in subsection 5.1. We restrict our attention to domestic banks because some of the data necessary to perform the robustness tests that we conduct in this subsection are not available for foreign banks.[20] We make changes to the panel of banks and add control variables. We also perform falsification tests to search for any changes in participation trends of LCR banks relative to non-LCR banks before an EWF was introduced. Overall, the baseline result holds: LCR banks increase their participation in the TDF after an EWF is added.

Table 7 shows robustness results for our main specification, presented in column 3 of table 4. By using column 3 of table 4 as the baseline for all robustness tests, we make all results comparable and keep this subsection concise.[21] Thus, all columns of table 7 show estimates of equation (1) using data from banks with assets between $25 billion and $100 billion.

Column 1 of table 7 restricts the data from column 3 of table 4 to observations from banks with minimum excess reserves of at least $10,000 in at least one of the operations. This restriction limits the sample to observations from banks with sufficient excess reserves to participate in at least one operation because, for all operations, $10,000 was the minimum bid.[22] Only one bank is eliminated from the sample and γ remains statistically significant and equal to 0.073, almost the same as the baseline result from table 4.

In addition to having sufficient excess funds to meet the minimum bid, a bank needs a location to settle funds from TDF transactions in order to participate. Any bank that is eligible to receive interest from the Federal Reserve can set up such a location. Thus, column 2 of table 7 restricts the

[20] Still, the robustness tests in columns 1 and 2 in table 7 can be replicated with the samples of domestic and foreign banks used in subsection 5.3. These tests show that the results from that subsection are robust too. These tests are available upon request from the authors.

[21] Still, robustness tests of other columns in table 4 show that those results are robust too.

[22] Given the amount of reserves in the banking system, it is relatively easy for banks to acquire excess reserves as desired. Therefore, including all banks in initial testing is not unreasonable.

Table 7: TDF Participation with Additional Bank Characteristics and Observations

	(1) Banks with assets between $25 billion & $100 billion, minium excess reserves	(2) Banks with assets between $25 billion & $100 billion, min. exc. res. & TDF access	(3) Banks with assets between $25 billion & $100 billion	(4) Banks with assets between $25 billion & $100 billion
LCRBank	0.136	0.247	0.143	0.058
	(0.094)	(0.184)	(0.084)	(0.098)
LCRBank × t	-0.024	-0.052	-0.019	-0.020
	(0.021)	(0.043)	(0.018)	(0.021)
LCRBank × t × EWF	0.073**	0.108*	0.060*	0.070**
	(0.028)	(0.043)	(0.024)	(0.026)
Bank characteristics?	No	No	No	Yes
All banks in organization?	No	No	Yes	No
Observations	328	215	392	344
Banks	23	15	28	24
R-squared	0.14	0.18	0.14	0.27

Note: This table shows robustness results for the estimates in column 3 of table 4. All columns of table 7 show estimates of equation (1) using a panel of domestic banks with assets between $25 billion and $100 billion. The dependent variable is a dummy variable equal to 1 if bank i submitted a tender in operation j and equal to 0 otherwise. $LCRBank_i$ is a dummy variable equal to one if the bank's holding company i is subject to either the standard or modified LCR requirement and zero otherwise. EWF_j is the indicator of whether operation j has an EWF, and t is an operation trend normalized to one in the first operation with an EWF. Column 1 restricts the panel to observations from banks with minimum excess reserves of at least $10,000 in at least one of the operations. Column 2 restricts the sample in column 1 to banks with an active location to settle TDF funds at the time of the TDF operation. In column 3, we present results after relaxing the lead bank panel restriction, as defined earlier as the largest bank affiliated with a bank holding company by total assets. Column 4 adds bank characteristics as control variables: return on assets, return on equity, total capital ratio, leverage ratio, net interest margin, total loan delinquency ratio, total net charge-offs ratio, excess reserves-to-assets, and HQLA-to-assets. Excess reserves are measured as averages over the two weeks prior to each TDF operation. All equations include operation fixed effects. Standard errors are clustered at the bank level and are shown in parentheses. * and ** denote significance at the 5 and 1 percent levels, respectively.

sample in column 1 to banks with an active location to settle TDF funds at the time of the TDF operation. The number of banks in the sample drops by one-third, and γ rises to 0.108. According to this estimate, LCR banks increased their participation rate by 10.8 percentage points relative to non-LCR banks in the first TDF operation with an EWF.

In column 3, we present results relaxing the lead bank restriction. In Section 3, we defined the lead bank as the largest bank affiliated with a bank holding company and we restricted the sample to banks that do not belong to a bank holding company and to the lead banks within bank holding

Table 8: Falsification Tests of TDF Participation Changing the EWF Introduction Date

	(1) Banks with assets between $25 billion & $100 billion, true date of EWF introduction	(2) Banks with assets between $25 billion & $100 billion, one operation before	(3) Banks with assets between $25 billion & $100 billion, two operations before
LCRBank	0.163	0.095	0.110
	(0.134)	(0.084)	(0.083)
LCRBank × t	-0.026	-0.016	-0.021
	(0.025)	(0.020)	(0.023)
LCRBank × t × EWF	0.071*	0.043	0.038
	(0.035)	(0.032)	(0.036)
Observations	258	257	256
Banks	24	24	24
R-squared	0.08	0.06	0.05

Note: This table shows robustness results for the estimates in column 3 of table 4. All columns of table 8 show estimates of equation (1) using a panel of domestic banks with assets between $25 billion and $100 billion. The dependent variable is a dummy variable equal to 1 if bank i submitted a tender in operation j and equal to 0 otherwise. $LCRBank_i$ is a dummy variable equal to one if the bank's holding company i is subject to either the standard or modified LCR requirement and zero otherwise. EWF_j is the indicator of whether operation j has an EWF, and t is an operation trend normalized to one in the first operation with an EWF. In column 1, EWF_j is constructed using the true date when an EWF was introduced in TDF operations, namely October 14, 2014, the ninth operation in the sample. Columns 2 and 3 present falsification tests in which EWF_j is constructed assuming an EWF was introduced in the eighth and in the seventh operation in the sample, respectively. Columns 1 to 3 use observations from the third to the fourteenth, the second to the thirteenth, and the first to the twelfth operation, respectively, to ensure that the regressions in all columns use observations from six operations before and six operations after the (true or false) date of introduction of an EWF. All equations include operation fixed effects. Standard errors are clustered at the bank level and are shown in parentheses. * and ** denote significance at the 5 and 1 percent levels, respectively.

companies. By relaxing this restriction, the number of banks included in the regression increases from 24 to 28. The coefficient estimate of 0.06 is significant and close to the original estimate in table 4. Column 4 of table 7 also uses the same sample of column 3 of table 4, but adds bank characteristics as control variables. Once again, the results remain about unchanged. On balance, these results show that the results from subsection 5.1 are robust.

We now perform falsification tests to search for changes in participation trends of LCR banks relative to non-LCR banks before an EWF was introduced. To perform these tests, we restrict the

data to the six operations immediately before the introduction of an EWF and the six operations immediately after, including the operation in which an EWF was introduced. This restriction ensures that the number of operations before and after the (true or false) date of introduction of an EWF is the same and that this number remains the same as we move that date from the true date to an earlier date. We then replicate the results from column 3 of table 4 using the true date of introduction and false earlier dates.

Table 8 presents the results. In column 1, EWF_j is constructed using the true date when an EWF was introduced in TDF operations, namely October 14, 2014, the ninth operation in the sample. Columns 2 and 3 present falsification tests in which EWF_j is constructed assuming an EWF was introduced in the eighth and in the seventh operation in the sample, respectively. Columns 1 to 3 use observations from the third to the fourteenth, the second to the thirteenth, and the first to the twelfth operation, respectively, following the data restriction described above.

The estimate of γ in column 1 is equal to the estimate in column 3 of table 4, 0.071, and also statistically significant, despite the data restriction imposed in table 8. When we compare the estimate of γ in column 1 of table 8 with the estimates in columns 2 and 3, we observe that the estimates decrease and are not significant as we move the date of introduction of an EWF from the true date in column 1 to one (0.043 in column 2) and two (0.038 in column 3) operations before. These falsification test support the assumption that changes in unobservable characteristics of banks before the introduction of an EWF do not drive our estimates of γ.

6 Conclusion

This paper shows that the LCR, a liquidity requirement for banks, affects their participation in the TDF, a Federal Reserve facility created to manage the aggregate quantity of reserves held by depository institutions. Our analysis suggests that banks subject to the LCR participate relatively more often than banks that are exempt from the LCR in TDF operations that allow banks to withdraw funds prior to maturity. LCR banks also increase the size of their bids in operations with an EWF compared to non-LCR banks. Thus, our results imply that liquidity regulation may affect bank demand in monetary policy operations.

More broadly, these results suggest that liquidity regulation may affect the transmission of

monetary policy through banks. Indeed, given that funds placed in term deposits are deducted from banks' excess reserves, the evidence that the LCR affects bank demand for term deposits indicates that the LCR also affects the demand for excess reserves. Consequently, this liquidity requirement should create a difference in the demand for excess reserves between banks subject to the LCR and other banks, which may determine how monetary policy is transmitted to the economy. In fact, Kandrac and Schlusche (2016) provide evidence that the transmission of monetary policy through bank lending varies across banks depending on the amount of excess reserves that each bank holds.[23] Together with their evidence, our work suggests that the LCR may affect the impact of monetary policy through banks by changing their demand for excess reserves.

Appendix A High-Quality Liquid Assets (HQLA)

In this appendix, we describe how we estimate HQLA. HQLA are estimated primarily using quarter-end balance sheet data reported in two regulatory filings, the Call Report (FFIEC 031 and FFIEC 041) and the Report of Transaction Accounts, Vault Cash and Other Deposits (FR 2900). Given the lack of granularity in the Call Report, the estimates tend to be conservative (low). In particular, the estimate does not include reverse repurchase agreements (also known as resale agreements).

The LCR requirement classifies HQLA into three types: level 1, level 2A, and level 2B. Level 1 assets consist of excess reserve balances, Treasury securities, and Ginnie Mae securities. Excess reserve balances are equal to reserve balances minus required reserves. Reserve balance data are from internal Federal Reserve accounting records, and the bank-level reserve balance requirement is calculated based on confidential filings of the FR 2900.[24] Treasury securities and Ginnie Mae securities are estimated using the risk-weighted assets schedule in the Call Report (RC-R Part II). Held-to-maturity securities, available-for-sale securities, and trading assets with a risk weight of zero percent are assumed to qualify as level 1 assets (*RCFDB604* + *RCFDB609* + *RCFDB628*).

Level 2A assets primarily consist of debt and mortgage-backed securities backed by Fannie Mae and Freddie Mac. These assets are estimated using securities with a risk weight of 20 percent (RC-

[23] In addition, the literature has shown substantial evidence that differences in other bank characteristics determine how monetary policy affects bank credit supply (Kashyap and Stein, 2000; Jiménez, Ongena, Peydró, and Saurina, 2014; Scharfstein and Sunderam, 2015; Dell'Ariccia, Laeven, and Suarez, 2016; Drechsler, Savov, and Schnabl, 2016).

[24] Excess reserves can be proxied using public data in the Call Report RC-A item 4 "Balances due from Federal Reserve Banks" (*RCFD0090*).

R Part II, *RCFDB605 + RCFDB610*).[25] Level 2B assets consist of corporate debt and equity. Given the ownership restrictions of banks, these holdings are small and are estimated using the securities schedule of the Call Report (RC-B). Specifically, we use item 6.a. "Other domestic debt" and include both held-to-maturity and available-for-sale (*RCFD1738 + RCFD1741*) securities.

According to the final rule, haircuts are applied to level 2 assets: the level 2A haircut is 15 percent, and the level 2B haircut is 50 percent. Thus, we estimate level 1, 2A, and 2B liquid asset amounts (LAA) as follows:

$$\text{Level 1 LAA} = \text{Excess reserves} + RCFDB604 + RCFDB609 + RCFDB628, \quad \text{(A.1)}$$

$$\text{Level 2A LAA} = 0.85 \times (RCFDB605 + RCFDB610), \quad \text{(A.2)}$$

$$\text{Level 2B LAA} = 0.50 \times (RCFD1738 + RCFD1741). \quad \text{(A.3)}$$

The LCR rule also imposes caps on level 2 LAA as a share of HQLA: Level 2B LAA assets cannot be more than 15 percent of a bank's total HQLA, and total Level 2 (2A + 2B) LAA cannot be more than 40 percent of total HQLA. We compute each bank's HQLA calculating the sum of their respective level 1, 2A, and 2B LAA based on equations (A.1) to (A.3) and subject to these caps.[26]

Appendix B A Model of TDF Participation

In this appendix, we present a simple model of participation in the TDF to illustrate how, under certain assumptions, variation between LCR and non-LCR banks and between operations with and without an EWF identify the shadow cost of the LCR.[27] We assume for simplicity that there are only two TDF operations, 0 and 1, such that only operation 1 has an EWF, that is, $EWF_0 = 0$ and $EWF_1 = 1$. Because there are only two periods, TDF participation by LCR and non-LCR banks do not have different time trends. Instead, an EWF causes a change in the level of participation of LCR versus non-LCR banks, which is measured by γ. This assumption does not impose any loss

[25] Note that risk-weighted asset definitions changed with Basel III. Beginning with the March 31, 2015, form, the items are level 1 = *RCFDD962 + RCFDD967 + RCFDD977* and level 2A = *RCFDD963 + RCFDD968*.

[26] See, for example, http://www.occ.treas.gov/topics/capital-markets/balance-sheet-management/liquidity/Basel-III-LCR-Formulas.pdf for formulas that can be used to calculate this sum.

[27] This model is based on a conference discussion of our paper by Adi Sunderam.

of generality and is intended only to keep the model simple. An extension of this model to include multiple periods, different trends in participation by LCR and non-LCR banks, and to allow the EWF to affect the trends in participation of LCR and non-LCR banks differently is straightforward, but would make the model more complicated and would not change the results materially given the purpose of this appendix.

We also impose assumptions that are not imposed in the empirical model used in the paper. These assumptions allow us to give an economic interpretation to the parameter identified by the differences-in-differences model. We assume that a bank decides whether or not to participate in the TDF comparing the benefits and costs of investing in the TDF as opposed to leaving the respective funds as excess reserves with the Federal Reserve. In particular, we assume that the probability that bank i participates in the TDF in operation j is given by:

$$\begin{aligned} Y_{ij} &= C_i + (RateTDF_j - IOER_j) - LiquidityCost_j \\ &\quad - ShadowCostLCR \times LCRBank_i \times (1 - EWF_j) + \varepsilon_{ij}, \end{aligned} \tag{B.1}$$

where C_i is a bank fixed effect, $RateTDF_j$ is the TDF interest rate, $IOER_j$ is the interest rate on excess reserves, and $RateTDF_j > IOER_j > 0$. $LiquidityCost_j$ is the liquidity cost of term deposits such that $LiquidityCost_0 > LiquidityCost_1 > 0$, where the first inequality holds because an EWF increases the liquidity of term deposits and thus lowers this cost, and the second inequality holds because even with an EWF, term deposits still include some liquidity cost. Liquidity costs in an operation with an EWF arise because funds can only be withdrawn prior to maturity subject to a penalty. Of note, we assume that $LiquidityCost_j$ does not depend on whether or not the bank is subject to the LCR. $ShadowCostLCR$ is the shadow cost for LCR banks of using excess reserves to invest in term deposits given that excess reserves count towards the LCR, while term deposits without an EWF do not. $LCRBank_i$ is, once again, an indicator of whether the bank is subject to the LCR. EWF_j and ε_{ij} are the same as in subsection 5.1.

Based on equation (B.1), the population differences-in-differences is the shadow cost of the

LCR:

$$\left(E\Big[Y_{ij}|LCRBank_i = 1, EWF_j = 1\Big] - E\Big[Y_{ij}|LCRBank_i = 0, EWF_j = 1\Big]\right) \quad - \\ \left(E\Big[Y_{ij}|LCRBank_i = 1, EWF_j = 0\Big] - E\Big[Y_{ij}|LCRBank_i = 0, EWF_j = 0\Big]\right) \\ = ShadowCostLCR. \tag{B.2}$$

This model can be extended to include multiple periods and a gradual effect of the EWF on participation in the TDF. In this case, γ could also be interpreted as the shadow cost of the LCR.

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