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Abstract

We study the effects of the US Federal Reserve's large-scale asset purchase programs during 2008-2014 on bank liquidity creation. Banks create liquidity when they transform the liquid reserves resulted from quantitative easing into illiquid assets. As the composition of banks' loan portfolio affects the amount of liquidity it creates, the impact of quantitative easing on liquidity creation is not a priori clear. Using a difference-in-difference identification strategy, we find that banks that were more exposed to the policy increased lending relative to a control group. However, while the increase in lending was present across all three rounds of quantitative easing, we only find a strong effect on liquidity creation during the last round. This points to a weaker impact of quantitative easing on the real economy during the first two rounds, when affected banks transformed the reserves created through the asset purchase program into less illiquid assets, such as real estate mortgages.

Keywords: Large-scale asset purchases, Quantitative easing, Liquidity creation, Bank lending

JEL codes: E52, E58, G21.

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1 Introduction

Starting with the 2008-09 Global Financial Crisis, a growing number of central banks have included large-scale asset purchase programs (LSAPs) in their toolkit of unconventional monetary policies. The US Federal Reserve, in particular, implemented several rounds of quantitative easing (QE) through which they purchased both agency mortgage-backed securities (MBS) and Treasuries securities.[1] The scale and unprecedented use of these unconventional policies has led to a large interest into understanding their effect on the banking sector and real economy. Empirical evidence thus far points to an effect of LSAPs on medium to long-term interest rates, through a signaling or portfolio-rebalancing channel (Krishnamurthy & Vissing-Jorgensen 2011, Gagnon et al. 2011, D'Amico et al. 2012, Maggio et al. 2016).[2]

Quantitative easing can also lead to an increase in credit supply through a classical bank lending channel, as banks gain new reserves and/or customer deposits, which are a relatively cheaper source of funding, and could result in a shift in the loan supply (Kashyap & Stein 2000, Butt et al. 2014, Kandrac & Schlusche 2017).[3] Yet, evidence on the impact of QE on bank lending is more confounded. Rodnyansky & Darmouni (2017) and Luck & Zimmermann (2020) find that banks increased overall lending after the first and third rounds of quantitative easing, with the first corresponding to mostly an increase in mortgage origination, while the third round to an increase in both real-estate, as well as commercial and industrial loans. Chakraborty et al. (2019), on the other hand, find that the increase in mortgage lending crowded-out the origination of commercial loans, the latter actually decreasing as a result of the Fed's asset purchase programs.

In this paper, we study the implications of this heterogeneous impact of QE on lending for bank liquidity creation, one of the most important *raison d'être* of financial intermediaries.[4] Banks

[1] The Federal Reserve implemented three rounds of QE: the first (QE1) started in November 2008, the second (QE2) in November 2010 and third (QE3) in September 2012.

[2] Under these channels, the central bank affects the relative supply of different assets, thereby lowering their yields and increasing the prices of current asset holdings of banks. The strength of the effect generally depends on the type of assets the central bank is purchasing. For instance, Maggio et al. (2016) find that, while loan interest rates decreased on average as a result of the policy, the decrease was substantially larger for assets that were conforming with the Government Sponsored Enterprises (GSEs)-guaranteed mortgages that the Fed was purchasing.

[3] Regardless of whether a bank or a bank customer is the ultimate seller of the securities purchased by the Federal Reserve through QE, the reserves created by the policy will be held by banks. If the seller is a bank, securities are simply swapped for reserves on the bank's balance sheet. If the seller is a non-bank entity, bank deposits will also increase by the amount of securities sold to the Fed.

[4] Modern theory of financial intermediation argues that banks exist to perform two central roles in the economy: create liquidity and transform risk (Diamond 1984, Ramakrishnan & Thakor 1984, Boyd & Prescott 1986). While risk transformation and liquidity creation sometimes coincide - for example when riskless liquid liabilities are transformed into risky illiquid assets-, bank liquidity creation is often seen as a distinct function of banks (Gorton & Pennacchi 1990, Gorton & Winton 2003).

create liquidity in the economy by financing relatively illiquid assets such as business loans with relatively liquid liabilities such as deposits (Bryant 1980, Berger & Bouwman 2009, 2015, Berger & Sedunov 2017). This important role of banks was the main focus of policymakers at the peak of the 2008 Global Financial Crisis, when large and explicit government support was granted to banks to support liquidity provision (Acharya & Mora 2015, Bai et al. 2018). However, while the impact of early measures such as the Troubled Asset Relief Program (TARP) in supporting market liquidity is well established, the role of later unconventional policies is less clear (Acharya & Mora 2015).

QE initially makes banks' balance sheets more liquid by purchasing assets and crediting the reserves account of banks with the Fed. Banks can then use this liquidity injection to invest in relatively more illiquid assets such as loans to businesses and individuals, thereby creating new liquidity in the economy. Crucial to our analysis are the types of loans given by banks, as their liquidity differs. For instance, classical measures of liquidity creation like Berger & Bouwman (2009) assume that loans that can be securitized and sold off the balance sheet, such as real estate mortgages, are less illiquid and, as such, lead to less liquidity creation in the economy. Similarly, banks can also "destroy" liquidity if the new reserves or deposits resulted from QE are not transformed into illiquid loans. Hence, the amount of liquidity created in the banking sector depends on the composition of the asset side of banks' balance sheets as a result of this policy intervention.

We thus investigate the impact of the Fed's quantitative easing programs on bank liquidity creation using a sample of US bank-holding companies during 2006-2014. In doing so, we study the distributional effects of QE *within* the balance sheet of financial intermediaries using a difference-in-differences identification strategy that follows Rodnyansky & Darmouni (2017) and Luck & Zimmermann (2020). This strategy exploits the cross-sectional variation in banks' exposure to the Fed's large-scale asset purchase programs. The underlying argument is that banks with a higher share of mortgage-backed securities in total assets benefited more from the program.[5] We employ several definitions based on the share of MBS-to-total assets prior to QE to classify banks into treated and control groups and investigate the differential effect

[5]There are several reasons why banks that held more mortgage-backed securities benefited more from the large scale asset programs. First, during the three waves of QE, the Fed focused on easing the deterioration in the MBS market by lowering yields and increasing the prices of banks' current asset holdings, thereby improving the balance sheets of banks that held higher shares of mortgage-backed securities. Second, banks with more MBS sold to the Fed saw a higher increase in reserves, which should have shifted their loan supply (Kandrac & Schlusche 2017). Third, banks with higher MBS holdings might have a different business model and will particularly increase their real estate lending as their liquidity position improves. Finally, since the QE programs were largely unanticipated, especially the third round, banks that held more MBS had a prompt recovery in stocks and an improved capital position (see Washington Post 2012).

of the policy across banks.

We first study the impact of QE and bank lending. Similar to previous work, we find that banks with a higher MBS-to-total assets ratio had a disproportionally larger increase in lending. This differential effect is present across all three rounds of QE, when treated banks had a larger increase in both real estate and commercial loans. However, while the increase in lending was present across all three rounds of QE, we only find a robust effect on liquidity creation during the third round, when the Fed purchased a large amount of MBS securities. During this last round, banks with a higher MBS-to-total assets ratio created 4.1% more liquidity relative to their size as compared to the control group. This implies that during the first two rounds treated banks transformed the reserves created by QE into less illiquid assets such as real estate mortgages, pointing to a weaker impact of the policy on the real economy.

Our main measures of liquidity creation follow those proposed by Berger & Bouwman (2009) and Bai et al. (2018), however our results are robust to different definitions of liquidity creation. Our findings also survive a battery of other robustness tests including various definitions of the treated and control groups, as well as controlling for bank-level variables. Furthermore, we include alongside bank fixed effects, year-quarter fixed effects to mitigate potential demand-side factors that can influence the composition of banks' loan portfolio and the amount of liquidity created on their balance sheets. Our work provides a novel and robust channel through which unconventional monetary policy can affect the function of the banking sector and its impact on the real economy.

The remainder of the paper is organized as follows. Section 2 presents related literature. Section 3 describes our conceptual framework and the mechanism we investigate. Section 4 discusses the data and identification strategy. Section 5 presents our results, while section 6 concludes.

2 Relation to literature

There is a growing empirical literature that studies the channels through which unconventional monetary policies such as quantitative easing are transmitted through the economy. These include the signaling channel (Krishnamurthy & Vissing-Jorgensen 2011, Bauer & Rudebusch 2014), portfolio-rebalancing channel (Gagnon et al. 2011, D'Amico & King 2013, Brunnermeier & Sannikov 2016) or reserves accumulation (Kandrac & Schlusche 2017, Butt et al. 2014).

A more recent literature looks at the effects of QE on bank lending. Rodnyansky & Darmouni (2017) exploit the cross-sectional variation of banks' exposure to mortgage-backed securities to show that banks with larger MBS holdings expanded lending more than their counterparts. This disproportional increase in lending appears to come from both real estate lending as well as corporate lending. Similarly, Luck & Zimmermann (2020) find that find that the first round of QE led to mostly an increase in mortgage origination, while in the third round both mortgage lending, as well as commercial and industrial loans increased. Chakraborty et al. (2019) also find that high-MBS banks increased mortgage origination disproportionally more. However, they also find that these banks reduced commercial lending suggesting a crowding out effect of QE. The main difference between Chakraborty et al. (2019) and Rodnyansky & Darmouni (2017) rests in the way QE is defined. We use both definitions in this paper. Furthermore, Maggio et al. (2016) shows that the type of assets purchased through QE has an impact on the type of loans originated. For example, QE1, which involved significant purchases of GSE-guaranteed mortgages, increased GSE-guaranteed mortgage originations significantly more than the origination of non-GSE mortgages. Kandrac & Schlusche (2017) show that reserves created by the Fed as a result of the first two QE programs led to higher total loan growth and an increase in the share of riskier loans within banks' portfolios. Butt et al. (2014), on the other hand, find little effect of QE on lending in the UK, since they show that the increase in deposits created by the policy was short-lived.

Our work complements these findings by focusing on a distinct channel through which QE might affect the real economy, i.e. liquidity creation. Liquidity creation is a key role of financial intermediaries that has been robustly linked to real economic growth (Berger & Sedunov 2017). A simple measure of liquidity creation is proposed in Deep & Schaefer (2004) as the difference between liquid assets and liquid deposits. The ability to honour the obligations associated with liquid deposits while having assets that are mainly illiquid is the classic liquidity transformation mechanism associated with modern fractional reserve banking. If, for instance, banks had to hold liquid assets to fully back every dollar of liquid deposits, then they would not really be involved in liquidity creation. Effectively, they would be acquiring liquid assets and holding them on behalf of their deposits, in a similar manner to a money market mutual fund. So measuring the gap between liquid deposits and liquid assets describes the extent of liquidity creation is occurring via banks.

A more sophisticated measure of liquidity creation is described in Berger & Bouwman (2009).[6] Similar to the Deep & Schaefer (2004) measure, liquidity is created when liquid deposits are

[6] This index of liquidity creation has been widely used among others, to examine the impact of bank capital on liquidity creation (Horváth et al. 2014, Kim & Sohn 2017), the role of bank regulation and governance (Jiang et al. 2016, Berger et al. 2016, Díaz & Huang 2017, Huang et al. 2018), or the role of monetary policy (Berger & Bouwman 2017).

used to finance illiquid assets such as loans. The measure thus assigns positive weights to all illiquid assets and liquid liability on and off the balance sheet of each bank, suggesting that banks that use liquid liabilities to finance illiquid assets create liquidity. Similarly, banks can also destroy liquidity when illiquid liabilities and equity are transformed into liquid assets. As such, these balance sheet items are assigned a negative weight. Moreover, since the degree of "liquidity" of a balance sheet item depends on how easily it can be sold or its maturity, Berger & Bouwman (2009) assign different positive and negative weights to various balance sheet items.[7] An even more sophisticated measure of liquidity creation is proposed in Bai et al. (2018), where these weights are time-varying and depend on market conditions that affect the liquidity of different asset classes. Given these classifications of assets and liabilities proposed by different measures of liquidity creation and the heterogeneous impact of QE on different types of loans suggested by previous research, the impact of the policy on liquidity creation is not obvious.

Finally, our work is also related to a recent literature that looks at how banks' liquidity positions affects lending, in particular during periods of bank distress. For instance, Cornett et al. (2011) find that banks with more illiquid asset portfolios, i.e., those banks that held more loans and securitized assets, increased their holdings of liquid assets and decreased lending following the collapse of Lehman Brothers in 2008. Similarly, Dagher & Kazimov (2015) find that banks more exposed to market liquidity shocks cut credit more for less liquid loans. They exploit the threshold above which a loan cannot be securitized and purchased by a government sponsored enterprises (GSE) as a cut-off for loan liquidity. Our work takes a new approach to understand how banks create liquidity by looking at the effect of policy interventions on this essential feature of financial intermediation.

3 Transmission mechanism

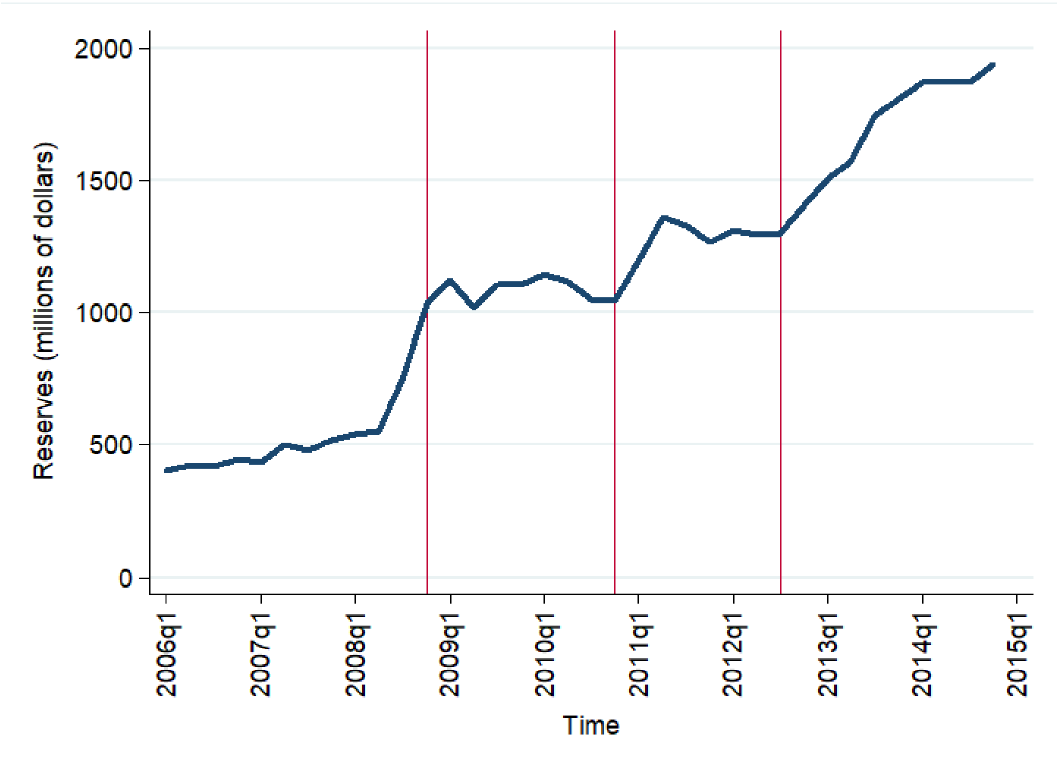
The Federal Reserve implemented three rounds of QE during 2008-2012 through which it purchased mortgage-backed and/or Treasury securities by crediting the reserves accounts of banks who sold (or whose customers sold) securities to the Fed.[8] If the final seller is a bank,

[7] As such the Berger & Bouwman (2009) metric is a more comprehensive measure of the liquidity transformation gap in Deep & Schaefer (2004). First, Berger & Bouwman (2009) includes off-balance sheet activities that are considered to be important contributors in liquidity creation by banks (Holmstrom & Tirole 1997, Kashyap et al. 2002). Second, Berger & Bouwman (2009) also classifies bank loans based on categories, rather than maturity.

[8] In the first round (QE1), from 2008Q4 (November) to 2010Q2 (June), Fed purchased $100 billion GSE debt (bonds issued by government-sponsored enterprise- Ginnie Mae, Fannie Mae, Federal Loans & Mortgage Corps, Freddie Mac) and $1,250 billion Mortgage-backed securities (MBS) ($500 billion non-agency MBS and $750 billion agency). The second round (QE2) was implemented from 2010Q4 (November) to 2011Q2 (June),

securities are simply swapped for reserves on the bank's balance sheet. If the seller is a non-bank entity, bank deposits will also increase by the amount of securities sold to the Fed. Thus, regardless who the ultimate seller of securities is, large scale asset programs result in an increase in bank reserves. This is evident in Figure 1 for our sample of banks. A notably sharper increase can be observed after QE3, which entailed the largest volume of purchased assets and, as a result, reserves creation.

Figure 1: Evolution of Total Reserves during QE



The figure shows the evolution of reserves for all US Bank Holding Companies in our dataset ranging from 2006Q1 to 2014Q4. The vertical lines indicate the beginning of each round of QE.

This significant injection of reserves should affect banks' optimal portfolio allocation by changing their liquidity profile and duration of assets (Joyce & Spaltro 2014, Kandrac & Schlusche 2017). This might, in turn, induce banks to engage in additional lending (see Bianchi & Bigio 2014, for a general equilibrium model). However, from the point of view of the amount of overall liquidity created in the banking sector, the composition of this increase in lending is important. Specifically, banks create liquidity when they transform liquid assets or liabilities into illiquid assets. However, different categories of assets have different degrees of illiquidity.

where the Fed purchased $600 billion Treasury bills. The third round (QE3) ran from 2012Q3 (September) to 2014Q3 (October) and included purchases of $40 billion MBS and $45 billion Treasury securities per month. At the end of the three rounds, the balance of the Fed contained $1.75 trillion MBS and $1.68 trillion Treasury bills.

For example, business loans are generally more illiquid than residential mortgages as the latter can often be more easily securitized and sold to meet liquidity needs (see Berger & Bouwman 2009). As we will show below, this has non-obvious implications for the amount of liquidity creation.

We use a simple example to illustrate the confounding effects of QE on the liquidity created by banks. Our main measure of liquidity creation follows Berger & Bouwman (2009) and classifies assets and liabilities into three categories: liquid, semi-liquid and illiquid. For assets, this depends on how easy and fast a bank can sell them to meet liquidity demands, while for liabilities, on how easy customers can withdraw their funds from the bank. Weights are then assigned to reflect the idea that liquidity creation occurs when the bank finances relatively illiquid assets with relatively liquid liabilities. Therefore, a weight of 1/2 is applied to illiquid assets and liquid liabilities. Conversely, a weight of -1/2 is applied to liquid assets and illiquid liabilities and a weight of 0 is assigned to semi-liquid assets and liabilities. Appendix B discusses in detail the construction of this liquidity index.

The example in Table 1 shows how liquidity creation following the definition above can be affected by QE. In this example a "Treated Bank" is one which sells MBS to the Fed for a value of, say, 100, which results in a corresponding increase in Reserves by 100. The "Control bank" is not affected by the asset purchase program, but we assume all banks have an increase in deposits of 10. Suppose the "Control bank" invests the 10 additional deposits in commercial and industrial (C&I) loans. This leads to a liquidity creation of 10 by transforming the most liquid liabilities (deposits), which have a weight of 1/2 in the Berger & Bouwman (2009) index, into the most illiquid assets (loans to enterprises), which are also assigned a weight of 1/2. We then analyze three different scenarios, where the Treated banks also invest the additional deposits of 10 in C&I loans, but differ in how they invest the new reserves created by the LSAP.

In Case 1, the Treated bank simply keeps the reserves on its balance sheet. Since the bank has substituted a relatively illiquid assets for a very liquid one, it is "destroying" liquidity according to the Berger & Bouwman (2009) measure, as the newly added reserves on the balance sheet of the bank are assigned a weight of -1/2. The total amount of liquidity destroyed is -40, as the bank created liquidity in the amount of 10 (by transforming 10 of liquid deposits into 10 C&I loans, as in the benchmark control bank) and destroyed liquidity in the amount of 50 ($-1/2 \times 100$) by substituting an illiquid asset with a very liquid one. Thus, QE, by making the asset side of banks' balance sheets more liquid, results in less liquidity being created in the financial sector if banks do not engage in additional lending.

Table 1: The impact of QE on liquidity creation: a simple example

Control bank

Assets	Liabilities
C&I Loans +10	Deposits +10

$LC = \frac{1}{2} \times 10 + \frac{1}{2} \times 10 = 10$

Treated bank (Case 1)

Assets	Liabilities
Reserves +100 *MBS -100* C&I Loans +10	Deposits +10

$LC = \frac{1}{2} \times 10 + \frac{1}{2} \times 10 - \frac{1}{2} \times 100 = -40$

Treated bank (Case 2)

Assets	Liabilities
Reserves +20 *MBS -100* C&I Loans +10 RE lending +80	Deposits +10

$LC = \frac{1}{2} \times 10 + \frac{1}{2} \times 10 - \frac{1}{2} \times 20 + 0 \times 80 = 0$

Treated bank (Case 3)

Assets	Liabilities
Reserves +0 *MBS -100* C&I Loans +60 RE lending +50	Deposits +10

$LC = \frac{1}{2} \times 60 + \frac{1}{2} \times 10 + 0 \times 50 = 35$

Treated bank (Case 4)

Assets	Liabilities
Reserves +0 *MBS -100* C&I Loans +0 RE lending +110	Deposits +10

$LC = \frac{1}{2} \times 0 + \frac{1}{2} \times 10 + 0 \times 110 = 5$

In Case 2, we assume the bank uses the reserves to fund mostly Real Estate (RE) loans. Since RE lending can be securitized and sold, it is considered a semi-liquid asset and is assigned a weight of 0. As such, in Case 2, the bank does not create any liquidity in the system. In Case 3, we assume that the bank uses all reserves to invest in both RE lending and C&I lending in equal shares. In this case, the level of liquidity created is greater than that of the control bank. Finally, Case 4 assumes that the QE program crowds out C&I lending by making real estate loans more appealing. In this case, the liquidity created is lower than the one of the control bank.

As this simple example shows, whether banks exposed to QE create more liquidity in the banking sector depends crucially on the distribution of assets on their balance sheet after the policy. If QE crowded out C&I lending as shown in Chakraborty et al. (2019), we should expect that treated banks created less liquidity as compared to the control ones. If banks increase both real estate and industrial lending, the amount of liquidity created depends on the relative size of each asset class. As such, the effect of QE on liquidity creation is not a priori clear.

4 Data and identification strategy

We obtain bank-level data from the *Consolidated Financial Statements for Bank Holding Companies (BHC)*, FR Y-9C quarterly reports that are filled by BHC with at least $500 million in total assets.[9] The FR Y-9C reports provide not only balance sheet data, but also capital positions, risk-weighted assets, securitization activities and off-balance sheet exposures, among others. Our sample consists of quarterly data from 2006:Q1 to 2014:Q4 and comprises 7,124 unique BHCs over this time frame. The number of BHCs varies across quarters due to different reporting requirements, with average of 1,200 BHCs reporting data in all quarters and 5,500 BHCs reporting only bi-annually (in Q2 and Q4).[10] Table 2 presents some descriptive statistics for key variables included in the dataset. We describe the construction and definitions of all variables in Appendix A.

Our main dependent variable is a measure of liquidity creation at the bank level following Berger & Bouwman (2009) (see Appendix B for details on the construction of this measure). Berger & Bouwman (2009) propose four measures of liquidity creation: (i) *cat fat*, which classifies assets and liabilities based on their type (liquid, illiquid and semi-liquid) and includes off-balance sheet items[11]; (ii) *cat non-fat* follows the same classification, but excludes any off-balance sheet items; (iii) *mat fat* defines assets and liabilities based on maturity/duration and

[9]The BHC data is obtained from the Federal Reserve Bank of Chicago at https://www.chicagofed.org/applications/bhc/bhc-home.

[10]Consolidated Report of Condition and Income (FR Y-9C) contains separate reporting for the parent company of large BHCs (FR Y-9LP) and parent company of small BHCs (FR Y-9SP). The number of observations varies from quarter to quarter because the Y-9SP is collected on a semiannual basis (in June and December). Since holding companies that file this report are included in those quarters, there is a significant increase in the number of observations for June and December. The first and third quarter only include banks that file the Y-9C and Y-9LP.

[11]Banks create liquidity off the balance sheet through guarantees that allow customers to draw-down liquid funds when needed (Kashyap et al. 2002).

Table 2: Summary Statistics

Variable	Mean	Standard Deviation	p25	p50	p75	Observations
Log (Assets)	14.2	1.33	13.35	13.76	14.52	36,989
Equity/assets	0.1	0.05	0.08	0.09	0.11	36,989
MBS/assets	0.1	0.09	0.027	0.077	0.14	29,810
MBS/securities	0.45	0.29	0.21	0.47	0.68	29,761
Securities/assets	0.2	0.12	0.11	0.18	0.26	36,989
Deposits/assets	0.78	0.12	0.75	0.81	0.85	34,468
Reserves/assets	0.06	0.057	0.023	0.037	0.072	36,989
Real estate lending/assets	0.5	0.16	0.41	0.52	0.61	36,989
C&I loans/assets	0.097	0.068	0.051	0.083	0.13	36,989
Total lending/assets	0.66	0.14	0.6	0.68	0.76	36,989
Realized gain/assets	-0.0002	0.04	0.00	0.00	0.0003	36,989
Unrealized gain/assets	0.0004	0.004	-0.0008	0.0003	0.002	35,577
Return on Assets (ROA)	0.03	0.69	0.01	0.02	0.03	36,989
Borrowings/ assets	0.122	0.11	0.06	0.1	0.15	34,468

Summary statistics recorded from 2006Q1 to 2014Q4 for all U.S. BHCs. All variables are at quarterly frequency. Variable definitions are provided in Appendix A.

includes off-balance sheet components and finally, (iv) *mat non-fat* includes a classification by maturity but excludes off-balance sheet items. As the authors argue, the most comprehensive measure is the *cat fat* one. This will also be our main measure of liquidity creation, but we will employ some of the other measures in robustness checks.

We also consider an additional liquidity measure based on Bai et al. (2018), called the Liquidity Mismatch Index (LMI). Similar to the previous measure, the LMI captures both asset (market liquidity) as well as liability side (funding liquidity). Market liquidity refers to the ease with which a bank can sell an asset, whereas funding liquidity is how quickly a bank can settle its obligations. Unlike the Berger & Bouwman (2009) measure, the weights of the various components in the LMI are time-varying and reflect the maturity mismatch between assets and liabilities. We follow Bai et al. (2018) and use their data on repo market haircuts and spreads (price-based measures) to construct the index. The measure is constructed to capture a maturity mismatch, i.e., how much cash the bank can raise against its balance sheet to withstand the cash withdrawals in case of a stress event in which all claimants seek to extract the maximum liquidity. Since our goal is to employ an index of liquidity creation and not mismatch, we change the signs of the weights accordingly. A description of the weights and construction of the index is presented in Appendix B.

Our identification strategy follows Rodnyansky & Darmouni (2017) and exploits the cross-sectional variation in MBS holdings across banks. This methodology relies on the assumption that banks that held more MBS on their balance sheet were more likely to be affected by the Fed's asset purchases. Several arguments support this claim. First, during the three waves of QE, the Fed focused on easing the deterioration in the MBS market by lowering yields and increasing the prices of banks' current asset holdings, thereby improving the balance sheets of banks that held higher shares of mortgage-backed securities. Second, banks with more MBS sold to the Fed saw a higher increase in reserves, which should have shifted their loan supply (Kandrac & Schlusche 2017). Third, since the QE programs were largely unanticipated, more affected banks witnessed an improvement in their market capitalization (see Washington Post 2012).

We measure a bank's exposure to QE by the ratio of MBS-to-total assets. Following Rodnyansky & Darmouni (2017), we define as the treatment group banks in the highest 25% of the MBS-to-total assets distribution, while those in the lowest 25% are included in the control group. To minimize endogeneity, banks are classified according to their MBS-to-total assets ratio in 2007:Q4, which is more than half a year before QE1. We also consider several alternative definitions for the assignment to treatment and control groups. First, we classify banks in the top decile of the distribution of MBS-to-total assets into the treatment group, while those in the bottom decile in the control. Second, we employ the ratio of MBS-to-total assets in 2007:Q4, which allows for an analysis of the entire sample of banks.

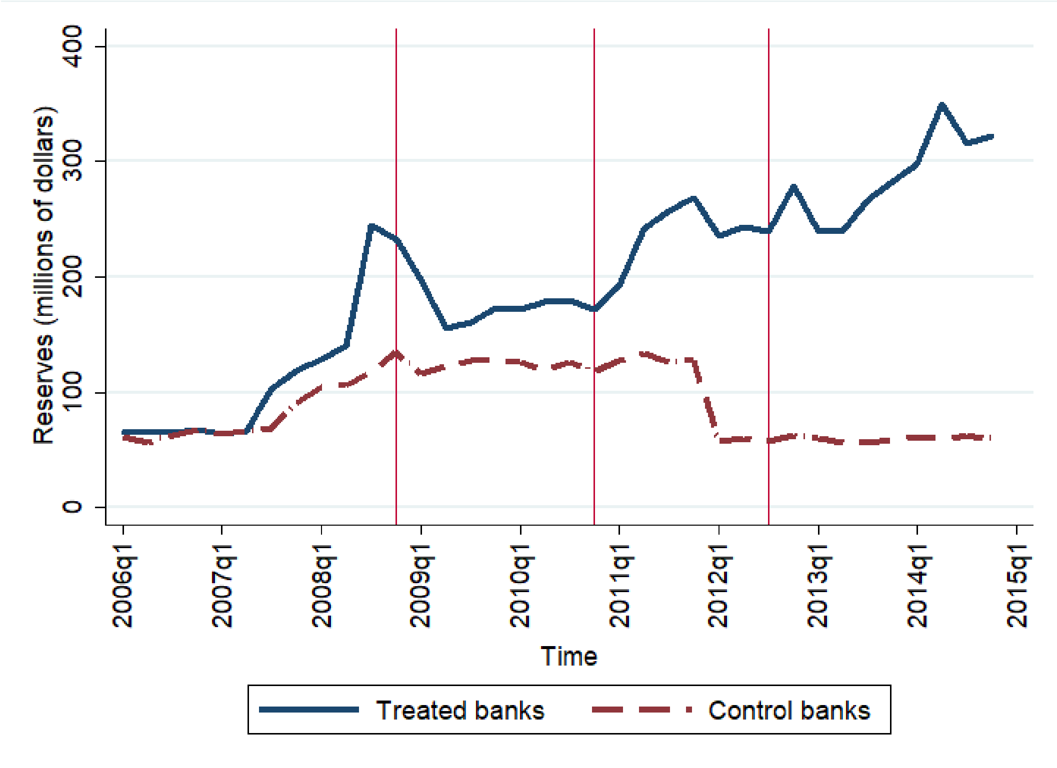
Table 3: Correlations between Treatment Group and Bank Characteristics

	$Treat_i$ (1)		$Treat_i^D$ (2)		$\left(\frac{MBS}{Assets}\right)_i$ (3)	
	coeff	SE	coeff	SE	coeff	SE
Log(Assets)	0.128***	[-0.033]	0.134***	[-0.046]	0.017***	[-0.004]
Tier 1 Capital	-0.019***	[-0.007]	-0.019**	[-0.008]	0.000***	[0.000]
Securities/Assets	2.329***	[-0.466]	2.247***	[-0.550]	0.509***	[-0.050]
Reserve/Assets	-2.070***	[-0.761]	-1.208	[-1.229]	0.01	[-0.085]
Lending/Assets	-0.073	[-0.489]	-0.115	[-0.537]	0.05	[-0.057]
Return on Assets	-0.152	[-2.360]	3.877	[-3.609]	0.075	[-0.238]
Log(Net Income)	-0.061**	[-0.025]	-0.086**	[-0.035]	-0.008***	[-0.003]
Constant	-0.388	[-0.639]	-0.298	[-0.854]	-0.328***	[-0.064]
Observations	455		182		964	
R-squared	0.479		0.600		0.484	

The table shows correlations between the treatment condition and bank characteristics in 2007Q4. $Treat_i$ is a dummy that takes the value one for banks in the 75^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the 25^{th} percentile. $Treat_i^D$ is a dummy that takes the value one for banks in the 90^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the 10^{th} percentile. $\left(\frac{MBS}{Assets}\right)_i$ is the ratio of MBS to Total assets in 2007:Q4. Robust standard errors in brackets. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

As shown in Rodnyansky & Darmouni (2017), the classification of banks into treatment and control is rather stable over time, as the level of MBS-to-total assets is fairly sticky. This alleviates the concern that banks might respond strategically to the LSAPs by increasing their holdings of mortgage-based securities. Nonetheless, it might be that banks in the treatment

Figure 2: Evolution of Total Reserves for Treated and Control Banks



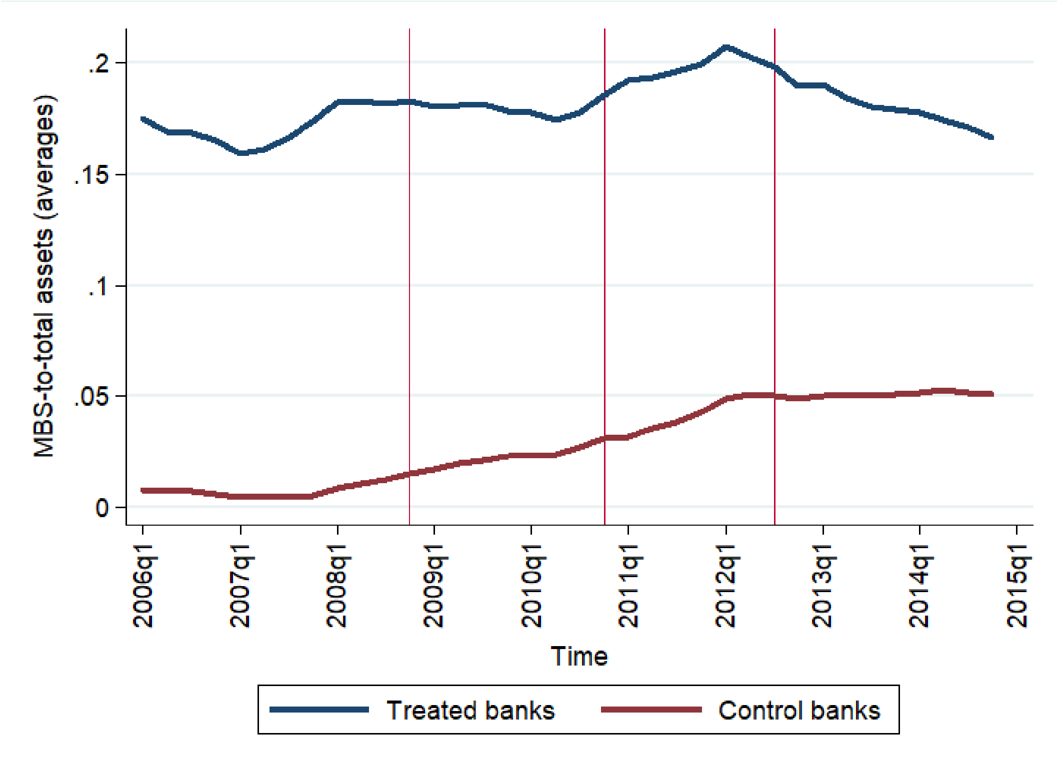
The figure shows the evolution of reserves for treated and control Banks. Treated banks are banks in the top 75^{th} percentile of MBS-to-total assets ratio in 2007Q4, while control are in the bottom 25^{th} percentile. The vertical lines indicate the beginning of each episode of QE.

and control groups are systematically different along a number of characteristics. To check this, we perform simple cross-sectional correlations between the treatment assignment variable and a number of bank characteristics. The results are presented in Table 3, where $Treat_i$ is the treatment definition based on quartiles (column 1), $Treat_i^D$ the one based on deciles (column 2), and $\left(\frac{MBS}{Assets}\right)_i$ is the ratio of MBS-to-total assets in 2007:Q4 (column 3).

These simple correlations suggest that banks that hold more mortgage backed securities tend to be different than control banks along several characteristics, which include size (log of assets), Tier 1 Capital ratio, the ratio of securities to total assets, and the log of net income. As such, treated banks are typically larger, more leveraged, hold more securities and have lower net income. We will thus control for these bank characteristics throughout our analysis.

The underlying argument behind our identification strategy is that banks with a higher share of mortgage-backed securities in total assets prior to QE (treated banks) benefited more from the program. Figure 2 shows the reserve accumulation by treated and control banks throughout the sample period. Clearly, we observe that banks in the treatment group witnessed a higher surge in reserves relative to control banks, potentially as a result of QE.

Figure 3: MBS-to-total assets for treated and control banks

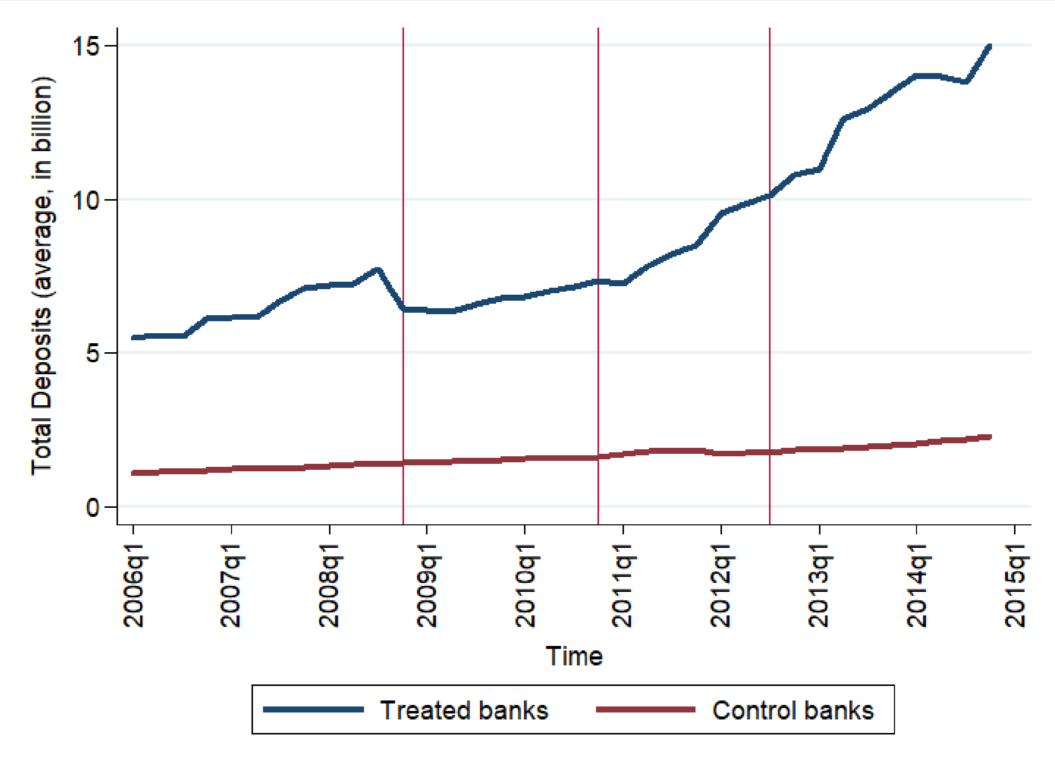


The figure maps the evolution of the ratio of MBS-to-assets for treated and control banks. Treated banks are banks in the top 75^{th} percentile of MBS-to-total assets ratio in 2007Q4, while control are in the bottom 25^{th} percentile. The vertical lines indicate the beginning of each episode of QE.

This differential evolution of reserves can be explained in two ways. First, treated banks who held more MBS before QE also sold more MBS to the Fed afterwards. Looking at Figure 3 that shows the evolution of the MBS-to-total assets of treated and control banks separately supports this argument: MBS holdings of treated banks (solid line) start to decline immediately after the implementation of QE, while control banks (dashed line) see an increase. Second, as most of sale of MBS to the Fed during QE actually came from non-bank entities, the pattern in Figure 2 could also be the result of treated banks having more clients that sold MBS to the Fed. Since only banks hold accounts with the Fed, sales of securities to the central bank by any institution transits through the balance sheet of a bank: the Fed credits banks reserve account, which leads to a build up of bank reserves and an increase in bank customers' deposits on the liabilities side of banks' balance sheets (Choulet 2015). Figure 4 shows that customer deposits did increase in the sample of treated banks, especially after QE2. That being said, it is clear that no single mechanism explains why banks with higher MBS were more affected by the Fed MBS purchases, rather this can be explained through a variety of distinct direct and indirect purchase mechanisms.

Our identification strategy exploits the cross-sectional variation in banks' exposure to the

Figure 4: Total deposits-to-total assets for treated and control banks



ThE figure shows the distribution of deposits-to-assets for treated and control banks. Treated banks are banks in the top 75^{th} percentile of MBS-to-total assets ratio, while control in the bottom 25^{th} percentile. The vertical lines indicate each episode of QE.

Fed's large-scale asset purchases via difference-in-differences regressions, as follows:

$$Y_{i,t} = \alpha_i + \beta_t + \gamma' QE\tau + \theta' Treat_i \times QE\tau + \delta' X_{i,t} + \epsilon_{i,t}, \quad (1)$$

where $Y_{i,t}$ is a measure of liquidity creation. $QE\tau = [QE1, QE2, QE3]$ is a vector of time dummies corresponding to the introduction of each QE episode. QE1 takes the value 1 during the period 2008:Q4 (November) - 2010:Q2 (June), QE2 from 2010:Q4 (November) - 2011:Q2 (June) and QE3 from 2012:Q3 (September) to 2014:Q3 (October), respectively. $Treat_i$ is an indicator variable and takes the value of 1 if a bank belongs to the treatment group and 0 if the bank belongs to the control group. $Treat_i \times QE\tau$ is an interaction term between a bank's treatment status and time dummies corresponding to each QE episode. The vector θ captures our coefficients of interest, namely the differential impact of each round of QE on liquidity creation in the treated as compared to the control group.

Vector $X_{i,t}$ includes a series of bank-level controls that capture differences in the scale and financial position of banks that might affect their lending activity (see Cornett et al. 2011, Berger & Bouwman 2013, Chakraborty et al. 2019). Particularly, we control for bank size, capital, profitability and level of securities, which were the main variables correlated to all treatment definitions. We control for bank fixed effects to remove all time-invariant differences across banks. Bank fixed effects also capture the average difference in liquidity creation between treated and control banks across the sample period. We also add year-quarter fixed effects to control for unobserved macroeconomic conditions that might affect both the demand and supply of bank loans.

5 Results

This section examines the impact of Federal Reserve's LSAP on lending behaviour of banks, and liquidity creation. First, we consider the effects of the three rounds of QE on lending, distinguishing between total lending, real estate (RE) loans and commercial and industrial (C&I) loans. Second, we present our main results pertaining to liquidity creation. Lastly, we present a series of robustness tests of our main results.

5.1 The impact of QE on bank lending

Motivated by previous literature, we first revisit the impact of QE on bank lending for our sample of bank holding corporations (BHCs). We follow closely the empirical strategy in Rodnyansky & Darmouni (2017) who use the Call Reports (FFIEC 031) data for a larger sample of BHCs over the period 2008-2014. We thus estimate the baseline difference-in-difference regressions in Equation (1), where we replace $Y_{i,t}$ with the logarithm of total lending, logarithm of real estate lending and the logarithm of commercial and industrial lending. We control for bank size, capital, profitability and level of securities, which were the main variables correlated with all treatment definitions. We also control for dummies capturing the three QE rounds that account for the impact of the policy on the lending behavior of all banks in the sample, as well as interaction between QE and the bank level controls to allow for possible heterogeneous responses to the intervention by BHCs.[12] Following Rodnyansky & Darmouni (2017) we employ two treatment definitions: (i) $Treat_i$ that takes the value of 1 if the bank is in the top 75^{th} percentile of MBS-to-total assets in 2007Q4 and a value of 0 if the bank is in the bottom 25^{th} percentile, and (ii) $\left(\frac{MBS}{Assets}\right)_i$ that is the ratio of MBS-to-total assets in 2007Q4.

The results are presented in Table 4. Columns (1)-(2) pertain to Total lending, while columns (3)-(4) to RE lending and (5)-(6) to C&I loans, respectively. Across both definitions of treated

[12]This empirical specification replicates Table 6 in Rodnyansky & Darmouni (2017).

Table 4: The impact of QE on bank lending

	Total Lending		**Real Estate Loans**		**C&I Loans**	
	(1)	(2)	(3)	(4)	(5)	(6)
$QE1 \times Treat_i$	0.032***		0.024*		0.060	
	(0.011)		(0.014)		(0.037)	
$QE2 \times Treat_i$	0.040***		0.029**		0.094**	
	(0.010)		(0.013)		(0.040)	
$QE3 \times Treat_i$	0.082***		0.070***		0.140***	
	(0.013)		(0.017)		(0.047)	
$QE1 \times \left(\frac{MBS}{Assets}\right)_i$		0.128***		0.273***		0.567***
		(0.049)		(0.068)		(0.181)
$QE2 \times \left(\frac{MBS}{Assets}\right)_i$		0.221***		0.408***		0.735***
		(0.056)		(0.076)		(0.229)
$QE3 \times \left(\frac{MBS}{Assets}\right)_i$		0.520***		0.786***		0.982***
		(0.101)		(0.093)		(0.275)
Observations	12,739	24,917	12,693	24,883	12,720	24,900
R-squared	0.833	0.866	0.776	0.748	0.264	0.321
QE	Yes	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
QE× Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

The dependent variable in Columns (1)-(2) is log of Total lending, in Columns (3)-(4) is the log of real estate loans and in Column (5)-(6) is the log of commercial and industrial loans. $Treat_i$ is a dummy that takes the value one for banks in the 75^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the 25^{th} percentile. $\left(\frac{MBS}{Assets}\right)_i$ is the ratio of MBS to Total assets in 2007Q4. $QE1, QE2, QE3$ are dummies for each QE wave. Bank-level controls include the log of Total Assets, Tier 1 Capital Ratio, the log of Net Income and the log of Securities. Constant terms included but not reported. Robust standard errors in parentheses. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

and control banks, we find that treated banks expanded total lending more than control banks. These effects are present across all three rounds of QE. With the natural logarithm of lending as the dependent variable, our estimates in column (1) suggest that QE1 boosted lending of treated banks by 3.2% relative to the control group, QE2 by 4%, while QE3 by 8.2%, respectively. These results are mostly consistent across both RE and C&I lending, and show a larger quantitative impact of the third round of QE.

Our results complement those in Rodnyansky & Darmouni (2017), however in their case, the effects appear stronger for QE1 and QE3 and more robustly related to an increase in RE lending as opposed to C&I loans. Our robustly estimated impact of QE on lending across all rounds of QE is most likely the result of our smaller sample of banks (we have 964 BHC with data on MBS/Assets in 2007Q4, as opposed to their sample of 3,949). Moreover, since our sample mainly includes the right tail of the bank distribution by assets, our results suggest that the lending effects might be stronger among these larger banks. This points to important heterogeneous effects of the policy across the banking sector and might shed some light on the mixed evidence in previous research (see Rodnyansky & Darmouni 2017, Chakraborty et al. 2019).

Table 5: The impact of QE on bank liquidity creation

	Liquidity creation to total assets			LMI to total assets		
	(1)	(2)	(3)	(4)	(5)	(6)
$QE1 \times Treat_i$	0.015*			0.014		
	(0.009)			(0.042)		
$QE2 \times Treat_i$	0.021**			0.075		
	(0.009)			(0.058)		
$QE3 \times Treat_i$	0.041***			0.103***		
	(0.014)			(0.040)		
$QE1 \times (\frac{MBS}{Assets})_i$		0.021			0.036	
		(0.065)			(0.173)	
$QE2 \times (\frac{MBS}{Assets})_i$		0.108			0.427*	
		(0.079)			(0.238)	
$QE3 \times (\frac{MBS}{Assets})_i$		0.250**			0.412**	
		(0.114)			(0.163)	
$QE1 \times Treat_i^D$			0.023**			0.136*
			(0.009)			(0.076)
$QE2 \times Treat_i^D$			0.023*			0.268**
			(0.013)			(0.106)
$QE3 \times Treat_i^D$			0.054***			0.167**
			(0.009)			(0.072)
Observations	12,751	24,936	5,125	12,751	24,936	5,125
R-squared	0.146	0.052	0.112	0.107	0.138	0.068
QE	Yes	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

The dependent variable in Columns (1)-(3) is ratio of the Berger & Bouwman (2009) measure of liquidity creation to total assets, while in Columns (4)-(6) it is the Bai et al. (2018) LMI index. $Treat_i$ is a dummy that takes the value one for banks in the 75^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the 25^{th} percentile. $Treat_i^D$ is a dummy that takes the value one for banks in the 90^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the bottom 10^{th} percentile. $(\frac{MBS}{Assets})_i$ is the ratio of MBS-to-total assets in 2007Q4. $QE1, QE2, QE3$ are dummies for each QE wave. Bank-level controls include Tier 1 Capital Ratio, the log of Net Income and the log of Securities. Robust standard errors in parentheses. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

5.2 QE and bank liquidity creation

We now turn our main empirical specification that estimates Equation 1 for the two main measures of liquidity creation we employ in this paper, namely the Berger & Bouwman (2009) *cat fat* measure and Bai et al. (2018) LMI index. We scale both dependent variables by total assets. The results are presented in Table 5. We employ three treatment variables that classify banks based on quantiles, deciles and the continuous measure of MBS-to-total assets.

As before, the main variable of interest is the interaction term between the QE time dummies and banks' treatment status. Our results are consistent across the two measures of liquidity creation we employ, suggesting they capture similar bank behavior. Overall, we find that treated banks created a disproportionally larger amount of liquidity in the banking sector, but mainly during the third round of QE. The interaction term between QE3 and the treatment status is the only one that is robustly estimated across the three definitions of treated banks. With the ratio of liquidity creation to total assets as the dependent variable, the estimates in

Table 6: The impact of QE on bank liquidity creation: matched sample

	Liquidity creation to total assets		**LMI to total assets**	
	(1)	(2)	(3)	(4)
$QE1 \times Treat_i$	0.076		0.472	
	(0.057)		(0.365)	
$QE2 \times Treat_i$	0.034*		0.637	
	(0.018)		(0.442)	
$QE3 \times Treat_i$	0.119***		0.644*	
	(0.042)		(0.377)	
$QE1 \times Treat_i^D$		0.142*		1.030*
		(0.085)		(0.569)
$QE2 \times Treat_i^D$		0.042		1.475*
		(0.036)		(0.814)
$QE3 \times Treat_i^D$		0.198***		1.288*
		(0.075)		(0.706)
Observations	12,751	5,125	12,751	5,125
R-squared	0.066	0.096	0.175	0.170
QE	Yes	Yes	Yes	Yes
Bank-level controls	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes

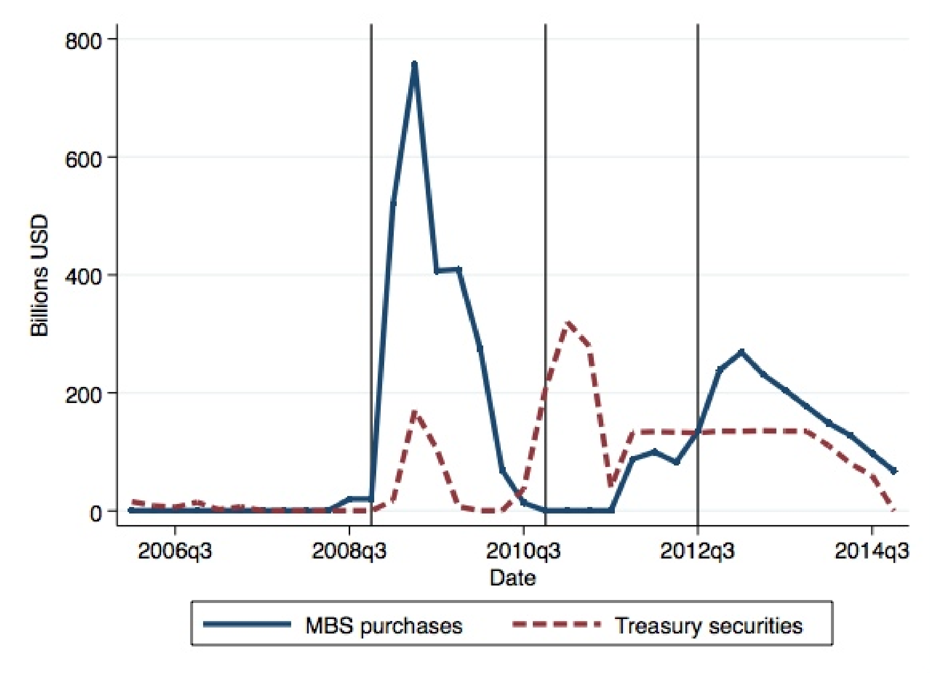
The dependent variable in Columns (1)-(3) is ratio of Berger & Bouwman (2009) measure of liquidity creation to total assets, while in Columns (4)-(6) it is the Bai et al. (2018) LMI index. $Treat_i$ is a dummy that takes the value one for banks in the 75^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the 25^{th} percentile. $Treat_i^D$ is a dummy that takes the value one for banks in the 90^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the bottom 10^{th} percentile. $QE1, QE2, QE3$ are dummies for each QE wave. Bank-level controls include Tier 1 Capital Ratio, the log of Net Income and the log of Securities. Robust standard errors in parentheses. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

column (1) suggest that, during QE3, treated banks created 4.1% more liquidity relative to their size as compared to the control group.

In our most conservative definition of treated banks that includes banks in the 90^{th} percentile of MBS/Assets versus those in the bottom 10^{th} (columns (3) and (6)), we find, as expected, a strong difference in liquidity creation across all the three rounds of QE. However, this includes only a small percentage of banks. These results, coupled with the ones in Table 4, suggest a strong heterogeneous impact of the LSAPs depending on bank characteristics, chiefly those related to size and securities holdings. Moreover, the results in Tables 4 and 5 suggest that, while banks with higher MBS/Total Assets were characterized by a disproportionally higher level of lending during all three rounds of QE, this increase in leading resulted in a higher liquidity creation only during QE3. This implies that, during the first two rounds, treated banks transformed the reserved created by QE into less illiquid assets such as RE loans, which points to a less important impact of the policy on the real economy.

As bank size seems to matter, we check the robustness of our results by employing a matching procedure that matches our treated and control groups by size, measured by the log of total assets. Banks are matched using propensity scores based on a logit model in 2007Q4 that

Figure 5: Quarterly purchase of MBS and Treasury securities by the Fed



The figure shows the quarterly amount of Mortgage-backed securities (MBS) and Treasury securities purchased by the Fed. The vertical lines indicate each episode of quantitative easing. The dashed line shows the amount of treasuries, whereas MBS are labelled as blue thick line.

relates the probability of being assigned to the treated group to their level of total assets. We consider the definitions of treatment groups based on the 75^{th} and 90^{th} percentile, respectively. We then employ this propensity score to re-weight treatment and control groups such that the distribution of bank size looks the same in both groups. This is done using the conditional probability of being in the treated group, $\hat{\lambda}$, to compute a weight as the odds ratio $\hat{\lambda}/(1-\hat{\lambda})$ (see Nichols 2007). We re-estimate the model in Equation 1 using the weighted data based on propensity scores. The results are presented in Table 6. As before, columns (1)-(2) refer to the Berger & Bouwman (2009) measure, while columns (3)-(4) to the Bai et al. (2018) LMI index. The estimations yields consistent results, with a strong differential impact on liquidity creation mainly present during QE3. As expected, the strong differences between control and treatment groups we found when comparing the 10^{th} versus the 90^{th} percentile, are less robust when we match banks by size, suggesting the effects in Table 5 were largely driven by large banks. Nonetheless, we still find a statistically stronger impact during QE3, in particular for the Berger & Bouwman (2009) measure.

5.3 Alternative identification strategy

An alternative identification strategy is proposed in Chakraborty et al. (2019) who investigate the impact of the Fed's LSAPs on bank lending and firm investment. They employ as main

Table 7: Chakraborty et al. (2019) identification strategy

	Liquidity creation to total assets				**LMI to total assets**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$MBS_{t-1} \times Treat_i$	0.002***				0.004			
	(0.001)				(0.006)			
$MBS_{t-1} \times Treat_i^D$		0.002**				0.009		
		(0.001)				(0.011)		
$TSY_{t-1} \times Treat_i$			0.001*				0.005**	
			(0.001)				(0.002)	
$TSY_{t-1} \times Treat_i^D$				0.001				0.000
				(0.001)				(0.003)
Observations	10,173	4,098	10,173	4,098	10,148	4,087	10,148	4,087
R-squared	0.059	0.041	0.056	0.038	0.111	0.070	0.111	0.070
Bank-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The dependent variable in columns (1)-(4) is the (Berger & Bouwman 2009) ratio of liquidity to total assets, while in columns (5)-(8) it is the Liquidity Mismatch Index (LMI) to total assets in (Bai et al. 2018). MBS_{t-1} and TSY_{t-1} are the of log amount of mortgage-backed securities Treasury securities purchased by the Fed during 2008-2014. $Treat_i$ is a dummy equal 1 for banks in the 75^{th} percentile of MBS-to-assets ratio in 2007Q4, and zero for those in the 25^{th} percentile. $Treat_i^D$ is a dummy equal 1 for banks in the 90^{th} percentile of MBS-to-assets ratio in 2007Q4, and zero for those in the 10^{th} percentile. Bank-level controls include the log of bank's net income, the log of securities, and Tier 1 risk-based capital ratio. Constant term included but not reported. Robust standard errors in parentheses. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

independent variable the actual amount of MBS and treasury securities purchased as opposed to time dummies corresponding to the introduction of each QE episode. Figure 5 shows these quantities in each quarter, which clearly identifies the start of the different QE rounds and how this alternative measure captures the scale of each QE program. Following Chakraborty et al. (2019), we interact the log amount of MBS and treasury purchases by the Fed in last quarter of year $t-1$ with our treatment dummies.

Table 7 presents the results using this alternative independent variable for our two measures of liquidity creation. Columns (1)-(4) correspond to the Berger & Bouwman (2009) measure, while columns (5)-(8) to the Bai et al. (2018) LMI index. We employ as treatment variables the classification of banks based on quartiles and deciles, respectively. The results for both measures of liquidity creation are positive, albeit less precisely estimated for the LMI index. The most robust evidence points to an impact on liquidity creation following MBS purchases, and less so following purchases of T-bills, which mainly occurred during QE2. This is in line with our previous results and Chakraborty et al. (2019), who also find an impact on lending mainly following MBS purchases. Yet, unlike Chakraborty et al. (2019), who find that real estate mortgages crowded out commercial loans, we find a consistently positive impact on liquidity creation.

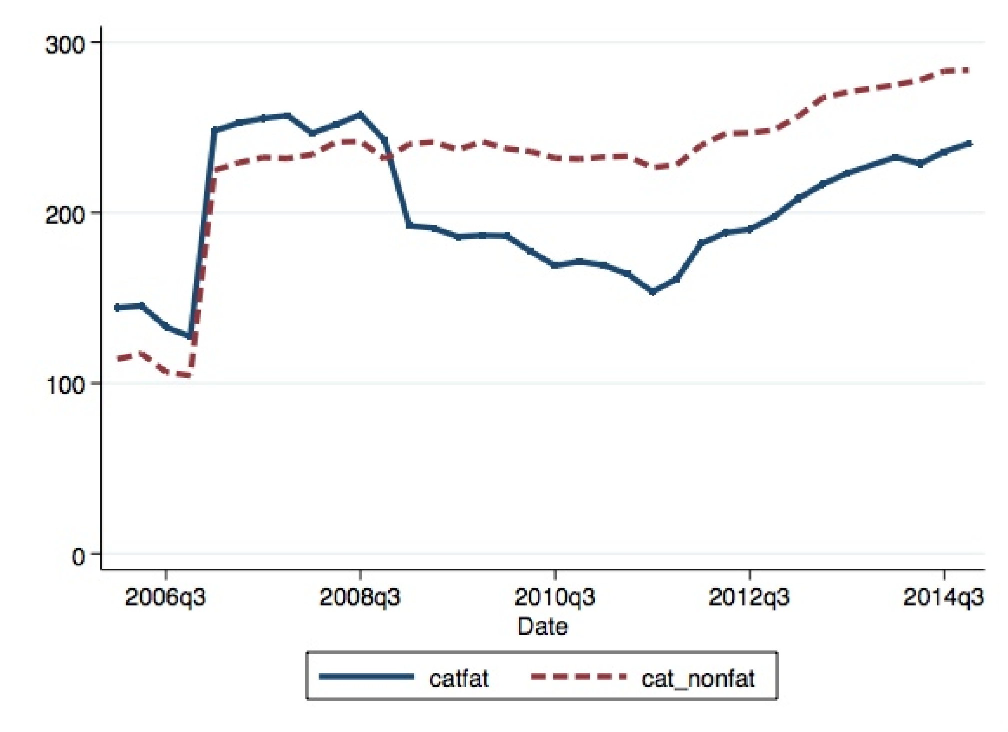
5.4 Other robustness checks

We perform a series of further robustness checks of our main results. First, we introduce a new treatment variable based on the mean values of MBS holdings to total assets. This dummy variable takes the value of 1 if a bank is in the top 50% of mortgage backed securities to total assets in 2007Q4 and 0 if it lies in the bottom 50^{th} percentile. The results are presented in Appendix Table 10 and are qualitatively similar to the ones obtained in our main specification, albeit less robustly estimated. We still find a stronger support for an differential increase in lending and liquidity creation during QE3.

Second, we conduct a sub-sample analysis by dropping observations in the first and third quarter in each year in which small BHCs that only file the FR Y-9SP do not report data. The results employing the different lending categories as dependent variable are only robustly estimated during QE3, while for liquidity creation we only find a significant result when employing the Berger & Bouwman (2009) measure of liquidity creation (see Appendix Table 11.)

Next, in Appendix Table 12, we consider alternative proxies for liquidity creation, namely the *cat nonfat* measure in Berger & Bouwman (2009) and the liquidity transformation gap proposed by Deep & Schaefer (2004). First, we construct the Berger & Bouwman (2009) *cat-nonfat* index (scaled by total assets) that includes loans based on category *(cat)* and excludes off-balance sheet items *(nonfat)*. Figure 6 shows that both measures of liquidity creation follow similar trends at the aggregate level: there in a spike just prior to the start of the 2008 Global Financial Crisis and followed by a sharp decline at the start of the crisis and a gradual increase afterwards. The increase is more pronounced after 2012 which corresponds to the start of QE3, particularly for the *cat fat* measure, which is the main one employed in our analysis. Nonetheless, we obtain consistent results when we employ the alternative dependent variable, suggesting that there was not a significant liquidity destruction off-balance sheet among treated banks (see Appendix Table 12). Second, we construct the measure of liquidity transformation in Deep & Schaefer (2004) as the difference between liquid liabilities and liquid assets, normalized by total assets. A higher liquidity transformation gap occurs when banks are largely financed by liquid deposits and hold mostly illiquid loans. Results in Appendix Table 12 suggest a significantly higher increase in liquidity transformation among treated banks across all three rounds of QE. This is not surprising considering the simpler concept of liquidity creation captured by this measure and the fact that lending was found to be disproportionally higher in all rounds of QE among treated banks (see Table 4).

Figure 6: Liquidity measures: *cat fat* and *cat nonfat*



The figure shows the evolution of the Berger & Bouwman (2009) *cat fat* (solid line) and *cat nonfat* (dashed line) liquidity measures. Both indices are scaled by total assets.

6 Conclusions

We study the effects of large scale asset purchases on bank liquidity creation. While existing evidence shows how LSAPs can affect bank lending, our work takes a new approach by looking at whether banks that benefited more from the Fed's three rounds of QE have also contributed more to the creation of liquidity in the economy.

We show that banks with higher share of assets in mortgage-backed securities prior to the start of program have increased both real estate and commercial loans disproportionally more following all three rounds of QE. However, not all types of loans contribute the same to liquidity creation, which increases more when banks give out more illiquid loans such as commercial lending. As such, we find evidence that treated banks contribute more to liquidity creation only the last round of QE which started in 2012 and when the Fed bought large amounts of MBS. Similar to previous evidence, our work points to important asymmetric effects of this unconventional monetary policy across banks and suggests that its impact on liquidity creation, as one of the main functions of the banking sector, was not strong across the entire duration of the program.

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A Variables employed: construction and corresponding definition in the Fed database

- **Treatment variable**: $\frac{MBS_{2007Q4}}{TotalAssets_{2007Q4}}$
- **Size:** log(Assets), where Assets= BHCK2170
- **Equity/Assets:** Equity= BHCK3210/ Assets= BHCK2170
- **Securities:** [held-to-maturity securities] BHCK1754 + [available-for-sale securities] BHCK1773
- **Treasuries:** [Trading Assets: Treasury Securities] BHCK3531
- **Deposits:** BHDM6631 [non-interest bearing deposits in domestic offices] + BHDM6636 [interest-bearing deposits in domestic offices] + BHFN6631 [non-interest bearing deposits in foreign offices] + BHFN6636 [interest-bearing deposits in foreign offices]
- **Reserves: cash and balances due from depository institutions:** BHCK0081 [non interest bearing balances and currency and coin] + BHCK0395 [interest bearing balances in U.S. offices] + BHCK0397 [interest bearing balances in foreign offices, Edge and Agreement subsidiaries, and IBFs]
- **Real estate lending/ Assets:** BHCK1410 [loans secured by real estate lending]/ BHCK2170 [Total assets]. BHCK1410 is the sum of BHCKF158, BHCKF159, BHDM1420, BHDM1797, BHDM5367, BHDM5368, BHDM1460, BHCKF160, BHCKF161 and BHDM1288.
- **Commercial and Industrial lending (C&I)/ Assets:** BHCK1763 [commercial and industrial loans to U.S. addressees] + BHCK1764 [commercial and industrial loans to non-U.S. addressees]/ BHCK2170
- Total Lending/ Assets: BHCK2122/ BHCK2170
- **Realized gains:** BHCK3521 [realized gain on held-to-maturity securities] + BHCK3196 [realized gain on available for sale securities]
- **Return on Assets:** BHCK4074 [net income]/ BHCK2170 [total assets]
- **Borrowings:** BHCK3300 [Total liabilities] – BHCK3210 [total equity capital] – (BHDM6631+ BHDM6636+ BHFN6631+ BHFN6636) [total deposits]

B Liquidity Creation:

One of the primary reasons that banks exist is because they create liquidity, through balance sheet activities, such as provisioning of loans to businesses and individuals or through off-balance sheet activities: loan commitments to their customers, extending letters of credit etc. In our analysis, we employ two indices of liquidity creation, namely, Berger & Bouwman (2009) measure and the Liquidity Mismatch Index (LMI) propose by Bai et al. (2018). Both the liquidity measures take into account the components of on and off-balance sheet including assets, liabilities, equity and off-balance sheet items such as loan commitments and derivatives. Both the liquidity creation measures take into account all bank activities (all assets including different types of loans based on category, all liabilities, equity capital and all off-balance sheet activities). Both measures also recognize that banks create liquidity, but can also destroy liquidity (Berger & Bouwman 2015). In addition, LMI also includes price-based measures such as, haircuts, spreads etc. LMI aims to measure the liquidity imbalances in the system and the amount of liquidity the Fed would have to provide to BHCs during crisis.

Table 8 presents the weights employed in the creation of these two indices. In Berger & Bouwman (2009), assets and liabilities are classified as liquid, semi-liquid and illiquid. The classification of loans is done through categories, and this measure also includes off-balance sheet items. The first step in LMI calculation involves assigning weights to the market liquidity of assets, which range from 0 (hard or time-consuming to sell, such as fixed assets) to 1 (very liquid items such as cash). The second step multiplies each initial weight by one minus the repo haircut of the asset class. The calculation of asset side weights includes haircuts as it measures how much cash can be borrowed against the asset. Then, haircut adjusted weights are multiplied by each asset category. Similarly, the same steps are repeated for funding liquidity of liabilities. The key difference occurs in the liability weights where they are assigned based on maturity. Each initial weight for liability is multiplied liquidity premium (spread between the overnight index swapped rate and Treasury bill rate). Since LMI is an indicator that measures mismatch of liquidity between assets and liabilities, we revise its weights to convert it into a liquidity creation measure by changing the sign to match that of the Berger & Bouwman (2009) index (see Column 5 in Table 8).

C Robustness tests

Table 8: Liquidity weights

Category	Sub- category	Weights in CAT-FAT	Weights in LMI (mean)	Revised LMI weights (mean)
Panel A: Asset-side weights				
Cash	Cash and balances due from depository institutions (Liquid)	-1/2	1	-1
	Federal funds sold (Liquid)	-1/2	1	-1
	Securities purchased under agreement to resell (Liquid)	-1/2	1	-1
Trading Assets/	Treasury securities (Liquid)	-1/2	.9661693	-.9661693
Available for sale	Agency securities (Liquid)	-1/2	.9671359	-.9671359
/ Held to maturity	Securities issued by state and U.S. Pol. Subdivisions (Liquid)	-1/2	.8312621	-.8312621
	Non-agency MBS (Liquid)	-1/2	.8672858	-.8672858
	Structural product (Liquid)	-1/2	.8672858	-.8672858
	Corporate debt (Liquid)	-1/2	.8290137	-.8290137
Available for sale	Equity securities (Liquid)	-1/2	.7790855	-.7790855
Loans	Loans secured by real estate		.7198426	.7198426
	Residential real estate loans (semi-liquid)	0		
	Commercial real estate loans (illiquid Assets)	1/2		
	Loans to finance agriculture (illiquid Assets)	1/2		
	Commercial and industrial loans (illiquid Assets)	1/2	1	1
	Other loans (illiquid Assets)	1/2	.7198426	.7198426
	Lease financing receivables (illiquid Assets)	1/2	.7198426	.7198426
	Consumer loans (semi-liquid)	0		
	Loans to depository institutions (semi-liquid)	0		
	Loans to foreign government (semi-liquid)	0		
Fixed Assets	Premises and fixed assets (illiquid Assets)	1/2	0	1
	Other real estate owned (illiquid Assets)	1/2	0	1
	Investment in unconsolidated subsidiaries (illiquid Assets)	1/2	0	1
Intangible Assets	Goodwill and other intangible assets (illiquid Assets)	1/2	0	1
Other Assets	(illiquid Assets)	1/2	0	1
Panel B: Liability-side weights				
Fed funds repo	Overnight federal funds purchased (Liquid)	1/2	-1	1
	Securities sold under repo (Liquid)	1/2	-1	1
Deposits	Deposits (Liquid)	1/2	-1.087827	1.087827
	Demand/ transaction deposits (Liquid)	1/2		
	Savings deposits (Liquid)	1/2		
	Time deposits (semi-liquid)	0		
Trading liabilities	Trading liabilities (Liquid)	1/2	-.9712813	.9712813
Other borrowed money	Commercial paper (semi-liquid)	0	-1.006757	1.006757
	With maturity <=1 year (semi-liquid)	0	-1.087827	1.087827
	With maturity >1 year (semi-liquid)	0	-1.674883	1.674883
Other Liabilities	Subordinated notes and debentures (Illiquid)	-1/2	-4.004571	-4.004571
	Other liabilities (Illiquid)	-1/2	-2.285964	-2.285964
Total Equity Capital	Equity (Illiquid)	-1/2	-.1565224	-.1565224
Panel C: Off balance sheet-side weights				
Contingent Liabilities- illiquid guarantees	Unused commitments (Illiquid)	1/2	-1.674883	1.674883
	Credit lines (Illiquid)	1/2	-4.004571	4.004571
	All other off- balance sheet liabilities	1/2		
Semi-liquid guarantees	Net credit derivatives (semi-liquid)	0		
	Net securities lent (semi-liquid)	0	-1.674883	1.674883
Liquid guarantees	Net participation acquired (Liquid)	-1/2		

Notes: 1. All securities regardless of maturity are taken as liquid assets under Berger-Bouwman index
2. Loans secured by real estate is a sum of residential and commercial real estate loans
3. Unused commitments include revolving, open-end loans, unused credit card lines, to fund commercial real-estate related loans, to provide liquidity to ABCP conduit structures, to provide liquidity to securitization structures, other unused commitments
4. Credit lines include financial standby letters of credit, performance standby letters of credit, commercial and similar letters of credit.
5. Haircut is the difference between asset's collateral value and its sale price.
6. Overnight index swaps (OIS) enable financial institutions to exchange fixed rate interest payments for floating rate payments based on specified principal amount.

Table 9: Chakraborty et al. (2019) identification strategy: Bank lending

	Total Loans		**Real estate loans**		**C&I Loans**	
	(1)	(2)	(3)	(4)	(5)	(6)
MBS	-0.007		0.016		-0.122**	
	(0.012)		(0.014)		(0.062)	
$MBS \times Treat_i^P$	0.004**		0.004		0.013**	
	(0.002)		(0.002)		(0.006)	
TSY		-0.014*		-0.005		-0.038
		(0.008)		(0.010)		(0.037)
$TSY \times Treat_i^P$		0.012***		0.010**		0.022
		(0.004)		(0.005)		(0.014)
Size	1.077***	0.991***	0.995***	1.003***	1.150***	1.070***
	(0.065)	(0.022)	(0.029)	(0.031)	(0.081)	(0.083)
Net Income	0.003	0.010***	0.004	0.005	0.022	0.029**
	(0.004)	(0.003)	(0.005)	(0.004)	(0.014)	(0.013)
Tier 1 Capital ratio	-0.000	-0.000	-0.000	-0.000	-0.000**	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	11,316	14,321	11,270	14,257	11,301	14,287
R-squared	0.740	0.781	0.581	0.616	0.230	0.224
Number of BHCs	963	971	961	968	960	968
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

Table presents coefficient estimates for BHCs' lending behaviour. Dependent variable in Column (1) and (2) is the log of total lending, Column (3) and (4) is the log of real estate loans and Column (5) and (6) is the log of corporate loans. MBS purchases is the lagged of log amount of mortgage-backed securities purchased by the Fed and TSY purchases is the lagged of log amount of treasury securities purchased by the Fed. We take Treated as the bank treatemnt status defined by top 75^{th} percentile of MBS-to-assets ratio in 2007Q4, while control group belongs in the bottom 25^{th} percentile. We include controls such as log of total assets (proxy for bank size), log of bank's net income and Tier 1 risk-based capital ratio (proxy for bank capitalization). Constant term included but not reported. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 10: Alternative treatment definition

	Bank Lending			Liquidity Creation	
	Total Loans	**RE**	**C&I**	**CATFAT/TA**	**LMI/TA**
	(1)	(2)	(3)	(4)	(5)
$QE1 \times Treat_i^M$	0.000	-0.001	0.017	-0.019	-0.005
	(0.004)	(0.006)	(0.016)	(0.015)	(0.026)
$QE2 \times Treat_i^M$	0.004	0.008	0.014	-0.002	0.030
	(0.006)	(0.008)	(0.021)	(0.018)	(0.035)
$QE3 \times Treat_i^M$	0.020**	0.027**	0.049*	0.012	0.039*
	(0.009)	(0.012)	(0.029)	(0.021)	(0.024)
Observations	24,929	24,883	24,900	24,936	24,936
R-squared	0.838	0.720	0.294	0.054	0.138
QE	Yes	Yes	Yes	Yes	Yes
Bank-level controls	Yes	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes	Yes

The dependent variable in column (1) is the log of Total lending, in column (2) the log of real estate loans, in column (3) corporate loans, in column (4) it is the ratio of Berger & Bouwman (2009) *cat fat* to total assets and finally in column (5) the ratio of Bai et al. (2018) LMI to total assets, respectively. $Treat_i^M$ is a dummy that takes the value one for banks that lie above the 50^{th} percentile of the MBS-to-total assets ratio, and zero for banks below the 50^{th} percentile. QE_t is a dummy variable for each QE wave, where t= 1,2,3. Bank-level controls include the log of Assets (in columns (1)-(3)), Tier 1 Capital Ratio, the log of Net Income and the log of Securities. Constant terms included but not reported. Robust standard errors in parentheses. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

Table 11: Restricted sample analysis

	Total Lending		Real Estate Loans		C&I Loans		CATFAT/TA		LMI/TA	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$QE1 \times Treat_i$	0.002		0.006		0.037		0.014		0.021	
	(0.007)		(0.010)		(0.026)		(0.009)		(0.070)	
$QE2 \times Treat_i$	0.006		0.010		0.023		0.020**		0.078	
	(0.009)		(0.011)		(0.032)		(0.010)		(0.089)	
$QE3 \times Treat_i$	0.023*		0.008		0.048		0.027**		0.114	
	(0.012)		(0.014)		(0.044)		(0.013)		(0.074)	
$QE1 \times (\frac{MBS}{Assets})_i$		-0.019		-0.046		0.179		0.008		0.064
		(0.053)		(0.062)		(0.183)		(0.059)		(0.290)
$QE2 \times (\frac{MBS}{Assets})_i$		0.019		0.044		0.136		0.090		0.453
		(0.048)		(0.065)		(0.182)		(0.076)		(0.371)
$QE3 \times (\frac{MBS}{Assets})_i$		0.204**		0.234**		0.403		0.207*		0.485
		(0.101)		(0.094)		(0.287)		(0.113)		(0.308)
Observations	6,158	11,999	6,136	11,977	6,149	11,984	6,161	12,002	6,161	12,002
R-squared	0.814	0.839	0.761	0.725	0.244	0.301	0.200	0.052	0.131	0.166
QE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The table presents estimates for a restricted sample that only includes Q2 and Q4. The dependent variable in Columns (1)-(2) is log of Total lending, in Columns (3)-(4) is the log of real estate loans and in Column (5)-(6) is log of corporate loans. $Treat_i$ is a dummy that takes the value one for banks in the 75^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the 25^{th} percentile. $(\frac{MBS}{Assets})_i$ is the ratio of MBS-to-total assets in 2007Q4. QE_t is a dummy variable for each QE wave, where t= 1,2,3. Bank level controls include the log of Total assets (in columns (1)-(6)), the log of Net income and securities and Tier 1 Capital ratio. Constant terms included but not reported. Robust standard errors in parentheses. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

Table 12: Alternative measures of liquidity creation

	***cat non-fat* to TA**			**Liquidity Transformation Gap**		
	(1)	(2)	(3)	(4)	(5)	(6)
$QE1 \times Treat_i$	0.004			0.011**		
	(0.005)			(0.006)		
$QE2 \times Treat_i$	0.010			0.023***		
	(0.006)			(0.007)		
$QE3 \times Treat_i$	0.023**			0.040***		
	(0.009)			(0.012)		
$QE1 \times Treat_i^D$		0.013			0.016*	
		(0.008)			(0.009)	
$QE2 \times Treat_i^D$		0.021*			0.032***	
		(0.011)			(0.011)	
$QE3 \times Treat_i^D$		0.026*			0.038**	
		(0.014)			(0.016)	
$QE1 \times (\frac{MBS}{Assets})_i$			-0.003			0.013
			(0.026)			(0.032)
$QE2 \times (\frac{MBS}{Assets})_i$			0.063*			0.124***
			(0.034)			(0.038)
$QE3 \times (\frac{MBS}{Assets})_i$			0.177***			0.294***
			(0.049)			(0.064)
Observations	12,751	5,125	24,936	12,751	5,125	24,936
R-squared	0.326	0.317	0.361	0.213	0.297	0.135
Number of id	482	192	964	482	192	964
QE	Yes	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year-Quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Bank Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

The dependent variable in Columns (1)-(3) is ratio of Berger & Bouwman (2009) *cat- nonfat* liquidity measure to total assets (TA), while in Columns (4)-(6) liquidity transformation gap in Deep & Schaefer (2004). $Treat_i$ is a dummy that takes the value one for banks in the 75^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the 25^{th} percentile. $Treat_i^D$ is a dummy that takes the value one for banks in the 90^{th} percentile of the MBS-to-total assets ratio, and zero for banks in the bottom 10^{th}. $(\frac{MBS}{Assets})_i$ is the ratio of MBS-to-total assets in 2007Q4. QE_t is a dummy variable for each QE wave, where t= 1,2,3. Bank-level controls include: Tier 1 capital ratio, log of net income and log of securities. Constant term included but not reported. Robust standard errors in parentheses. ***, **, * represent significance at the 1%, 5% and 10%, respectively.

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