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The implications of liquidity regulation for monetary policy implementation and the central bank balance sheet size: an empirical analysis of the euro area

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Abstract

We analyse the impact of the Liquidity Coverage Ratio (LCR) on the demand for central bank reserves in the euro area with difference-in-differences estimation techniques. Using a novel dataset and an identification strategy that exploits the cross-country heterogeneity in the regulatory treatment of reserves for LCR purposes prior to the announcement of a harmonised euro area standard as a quasi-natural experiment, we find evidence that points to LCR-induced demand for reserves. Specifically, our results suggest that banks with low LCRs relative to peers increased their central bank reserve holdings as a result of the LCR regulation. Our findings have economically meaningful implications for the operational framework of monetary policy and imply that the Eurosystem's balance sheet may need to remain larger than it was prior to the financial crisis and the associated introduction of new liquidity regulation.

Keywords: Basel III, Liquidity Coverage Ratio, monetary policy, central bank operational framework, ECB

JEL classification: C23, E52, G28

Non-technical summary

Following the financial crisis, the global regulatory framework for the banking sector was strengthened by the introduction of Basel III. Among the regulations included in this internationally agreed set of measures is the Liquidity Coverage Ratio (LCR), which aims to ensure that banks have a sufficient stock of high-quality liquid assets (HQLA) that can be converted into cash easily and immediately in order to meet liquidity outflows over a 30-day stress scenario. Among the HQLA treated most favourably in the LCR framework are the exposures of commercial banks to central banks, making reserve accumulation a way for banks to improve their LCRs. The LCR regulation therefore has the potential to structurally increase the demand for central bank reserves.

We empirically assess whether or not the LCR increased demand for central bank reserves in the euro area. Our analysis has important implications for monetary policy: higher reserve demand can affect short-term interest rates and bidding behaviour in central bank open market operations. In order to ensure an alignment of money market rates with key policy rates and thereby preserve a smooth implementation and transmission of monetary policy, the central bank may need to increase the supply of reserves. Our paper contributes to the limited body of literature on the interactions between regulation and monetary policy and, to our knowledge, is the first paper that empirically assesses the impact of liquidity regulation on the demand for reserves in the euro area.

To identify the impact of the LCR on reserve demand, we exploit the announcement of a harmonisation of the regulatory treatment of reserves for LCR purposes in the euro area in 2015 as a quasi-natural experiment. Prior to the harmonisation of treatment, the EU legislation that introduced the LCR into law was interpreted at the national level and reserves were treated differently across countries for the purposes of calculating the LCR. We obtain information on this national regulatory treatment from an internal Eurosystem survey of national central banks conducted in mid-2014. Based on this survey, we identify a group of countries for which the harmonised regulatory treatment increased the value of reserves for LCR purposes and a group of countries for which the harmonised regulatory treatment was the same as the pre-existing national treatment. We consider banks located in the former set of countries a “treatment group” and banks in the latter set of countries a “control group”.

We base our analysis on a novel and proprietary dataset consisting of quarterly observations from 2014Q1 to 2016Q4 for a sample of 86 significant euro area banking groups supervised by the Single Supervisory Mechanism. First, we estimate the impact of the LCR regulation on reserve demand using a difference-in-differences approach to compare reserve accumulation in the treatment and control groups after the harmonisation announcement. Second, we use a difference-in-difference-in-differences (triple differences) approach to estimate the impact of the LCR regulation on reserve demand conditional on the degree of compliance with the LCR requirement just before the harmonisation announcement.

We find that the LCR regulation did not change the relative demand for reserves on an aggregate basis between banks in the control and treatment groups, but it did increase the demand for reserves amongst banks with LCRs that were in the lowest quartile of the sample in the period just before the harmonisation announcement. Our results hold even after controlling for the supply-driven increase in reserves to the banking sector via the asset purchase programme, cross-country differences in the opportunity cost of holding central bank reserves, bank size and banks' leverage ratios. Specifically, our baseline analysis shows that the LCR regulation increased demand for reserves amongst euro area banks with low LCRs relative to their peers by an amount of between at least €103 billion and €150 billion on average over the six quarters following the harmonisation announcement. This is economically meaningful when compared with the quantity of reserves supplied to the banking sector by the Eurosystem via monetary policy operations before the financial crisis of around €450 billion.

We conclude that the implementation modalities of monetary policy should remain flexible enough to respond to changes over time in the regulatory demand for reserves in order to safeguard the controllability of short-term money market rates and thereby the smooth transmission of monetary policy. Hence, at least some of the changes in the operational framework of the European Central Bank (ECB) introduced since 2008 may need to be retained, and the size of the Eurosystem's balance sheet could remain structurally larger than it was prior to the financial crisis and the associated introduction of new liquidity regulation.

1. Introduction

Following the financial crisis, the Basel Committee on Banking Supervision strengthened the international regulatory framework for the banking sector. These reform measures, known as Basel III, consist of both capital and liquidity regulations, including the Liquidity Coverage Ratio (LCR). Under the LCR regulation, banks are required to hold an adequate stock of unencumbered high-quality liquid assets (HQLA) to meet their expected net cash outflows over a 30-day stress scenario. The LCR regulation was introduced into EU law through the Capital Requirements Regulation (CRR) in 2013 and was gradually phased in between October 2015 and January 2018, when the final minimum requirement of 100% took effect.[1] Among the HQLA treated most favourably in the LCR regulation are commercial banks' exposures to central banks, thereby making reserve accumulation a means of improving the LCR.[2] The LCR regulation therefore has the potential to structurally increase the demand for central bank reserves.

Using a unique and proprietary dataset available at the European Central Bank (ECB), we empirically assess whether or not the LCR increased demand for central bank reserves in the euro area. Higher reserve demand can affect short-term interest rates and bidding behaviour in central bank open market operations (see BIS Committee on the Global Financial System, 2015). In order to ensure an alignment of money market rates with key policy rates and thereby preserve a smooth implementation and transmission of monetary policy, the central bank may need to increase the supply of reserves. Our paper therefore contributes to the limited body of literature on the interaction between regulation and monetary policy at a time when central banks in advanced economies are reflecting on the future design of their operational frameworks.[3]

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[1] $LCR = \frac{Stock\ of\ HQLA}{Total\ expected\ net\ cash\ outflows\ over\ next\ 30\ calendar\ days}$. The minimum LCR under the CRR is: 60% from 1 October 2015, 70% from 1 January 2016, 80% from 1 January 2017 and 100% from 1 January 2018.

[2] The stock of HQLA consists of level 1 and level 2 assets. In the EU, a minimum of 60% of a bank's liquidity buffer must consist of level 1 assets, most of which are not subject to any haircuts in the calculation of liquidity buffers. Level 1 assets include coins and banknotes, central bank reserves held by credit institutions that are withdrawable during stress periods, claims on or guaranteed by central or regional governments and certain high-quality covered bonds. Level 2 assets are divided into two subsets, levels 2A and 2B, depending on their liquidity characteristics. The market value of level 2A assets is subject to a haircut of at least 15% while level 2B assets are subject to minimum haircuts of between 25% and 50%. For further details on level 1 and level 2 assets, see Articles 10-13, EU Delegated Regulation 2015/16.

[3] For example, the ECB launched a review of its monetary policy strategy in January 2020. The 2016 Jackson Hole Symposium of the Federal Reserve Bank of Kansas was entitled "Designing Resilient Monetary Policy Frameworks for the Future" and included participants from several central banks, many of which made reference to the relevance of new regulation. See also Bank of England (2018).

To identify the impact of the LCR on reserve demand, we exploit the announcement of a harmonisation of the regulatory treatment of reserves for LCR purposes in the euro area as a quasi-natural experiment. Before the harmonisation of treatment, national central banks (NCBs) within the Eurosystem interpreted the liquidity regulation encompassed in the CRR at their discretion. Some countries classified all central bank reserves as HQLA while others considered only reserves in excess of minimum reserve requirements as HQLA, thereby giving rise to differences in the treatment of reserves in the LCR numerator. In addition, some countries considered reserve requirements as a liquidity outflow, affecting the LCR denominator. For some countries, the harmonised regulatory treatment of reserves was effectively identical to the existing national treatment, while for others, the harmonisation of treatment increased the regulatory value of reserves. Banks in the former set of countries are considered the “control group” and banks in the latter set of countries are considered the “treatment group”.

Our analysis consists of two steps. First, we estimate the impact of the LCR regulation on reserve demand using a difference-in-differences (DiD) approach to compare changes in reserve accumulation between banks in the treatment and control groups after the pre-announcement of the harmonised regulatory treatment by the German Federal Financial Supervisory Authority in July 2015. Second, we use a difference-in-difference-in-differences (triple differences) approach to estimate the impact of the LCR regulation on reserve demand conditional on the degree of compliance with the fully phased-in LCR requirement just before the pre-announcement of the harmonised treatment.

Our first set of results shows no significant difference between the two groups, meaning that the introduction of the LCR regulation did not change the relative demand for reserves on an aggregate basis in countries where the harmonisation of treatment increased the regulatory value of reserves. Our second set of results suggests that banks with a low LCR relative to peers increased their demand for reserves in response to the LCR regulation. For banks with LCRs that are below 130%, which encompasses the lowest quartile of both the treatment and control groups, we find a statistically significant difference between the two groups, with low-LCR banks in the treatment group accumulating, on average, more reserves after the harmonisation announcement. The results hold even after controlling for potential covariates, namely the exogenous provision of liquidity to the baking sector via the Eurosystem’s asset purchase programme (APP), cross-country differences in the opportunity costs of holding central bank reserves, bank size and banks’ leverage ratios.

At the same time, it is important to acknowledge the caveats of the analysis. When reducing the LCR threshold to 120%, the results are only robust when control variables are excluded, indicating the importance for the analysis of retaining all banks with LCRs in the lowest quartile of the sample distribution. In addition, data limitations prevent us from conducting the analysis at the individual bank level. Hence, while our results hold at banking group level, we are unable to test their robustness at individual level.

Our findings provide empirical support to the theoretical work of Bech and Keister (2017) and Duffie and Krishnamurthy (2016), who argue that the LCR is likely to only exert tangible effects on behaviour to the extent that it is, or could become, binding. As discussed by Bonner and Eijffinger (2016), the magnitude and extent of over-compliance with the LCR suggests that liquidity regulation can be viewed as effectively binding at levels above the minimum requirement of 100%. The fact that we find an impact of the LCR at levels below 130% is consistent with the widespread tendency of banks to hold regulatory buffers. This phenomenon has been attributed in the literature to the effectiveness of market discipline (Fonseca and González, 2014; Flannery and Rangan, 2008; and Nier and Baumann, 2006), as well as to the preference of banks to reduce the likelihood of non-compliance (Berger et al., 2008) and to signal their strength relative to peers (Lindquist, 2004 and Baldo et al., 2018).

Our analysis has important and economically meaningful implications for monetary policy, with the baseline results pointing to regulatory demand for reserves in the range of between at least €103 billion and €150 billion on average over the six quarters following the announcement of a harmonisation of treatment. This is sizeable when compared with the circa €450 billion of reserves provided by the Eurosystem to the banking sector via monetary policy operations prior to the crisis, as determined by the size of the liquidity deficit arising from autonomous factors and reserve requirements.[4] We conclude that the implementation modalities of monetary policy should remain flexible enough to respond to changes over time in the regulatory demand for reserves in order to safeguard the controllability of short-term money market rates. It follows that at least some of the changes in the ECB's operational framework introduced since 2008 may need to be retained, and the size of the Eurosystem's balance sheet could remain structurally larger than it was prior to the financial

[4] Autonomous factors affect the liquidity position of the banking sector but are outside of the control of the central bank. The largest factors in the euro area are banknotes in circulation and official sector deposits with the Eurosystem (see ECB, 2002 and ECB, 2013).

crisis and the associated introduction of new liquidity regulation. These findings are particularly relevant in the context of the review of the European Central Bank’s monetary policy strategy.

Given our results, a return to pre-crisis monetary policy implementation modalities could be associated with more aggressive bidding behaviour in open market operations and an insufficient supply of reserves to the banking sector. Prior to the financial crisis, the Eurosystem conducted open market operations with variable-rate tender procedures and allotted just enough reserves to cover the liquidity deficit on average during a maintenance period. The operational framework ensured neutral liquidity conditions and an anchoring of money market rates to the middle of the interest rate corridor. Since the financial crisis, the Eurosystem has operated in an environment of excess liquidity owing to the adoption of fixed-rate tender procedures with full allotment for refinancing operations and various asset purchase programmes (Bindseil, 2014). Our results suggest that regulatory demand for reserves could constitute a new autonomous factor that structurally increases the liquidity deficit and therefore requires consideration in the calibration of central bank liquidity provision in order to ensure that short-term interest rates can be steered in line with the intended monetary policy stance.

Our paper contributes to the nascent literature on the interaction between regulation and monetary policy and is, to our knowledge, the first paper that empirically assesses the impact of liquidity regulation on the demand for reserves in the euro area. Our findings support the theoretical model-based conclusions of Bech and Keister (2017) and Körding and Scheubel (2018), as well as the conceptual findings of Bindseil and Lamoot (2011) and Schmitz (2013), that the LCR regulation could have substantial implications for the implementation of monetary policy.

Related empirical work also finds important links between liquidity regulation and monetary policy. Bonner and Eijffinger (2016) assess the impact of Dutch liquidity requirements that were in place prior to the introduction of the Basel III LCR on the interbank money market and bank intermediation in the Netherlands. They find that the liquidity requirement increased money market interest rates as well as banks’ demand for interbank funding with maturities longer than 30 days. Banerjee and Mio (2018), using the heterogeneous implementation of liquidity regulation in the United Kingdom as a means of identification, find that banks subject to the regulation altered the composition of both their assets and liabilities: on the assets side, banks significantly increased their share of HQLA to total assets, mainly via an increase in central bank reserves.

In the case of the United States (US), Rezende et al. (2016) estimate the effects of the LCR on participation in the Federal Reserve's Term Deposit Facility (TDF), which is a tool created to manage the aggregate quantity of reserves held by depository institutions. They find that the participation of banks subject to the LCR in the TDF increased when term deposits became LCR-eligible. Ihrig et al. (2017) show that large US banks initially increased excess reserves as they moved to comply with the LCR regulation, but some banks subsequently adjusted the composition of their HQLA stock in favour of Treasuries and mortgage-backed securities. They find that this post-compliance shift in the composition of HQLA is consistent with optimal portfolio theory, whereby banks optimise their liquid asset holdings subject to risk-return considerations. In other work on the LCR and securities prices, Fuhrer et al. (2017) find evidence of an HQLA premium. Using the introduction of the LCR in Switzerland as a quasi-natural experiment, they find that the announcement of the detailed LCR principles increased the price differentiation between HQLA and non-HQLA securities.

In Section 2, we explain our estimation strategy and data. In Section 3, we present the main results together with various robustness tests. In Section 4, we conclude by discussing the policy implications of our analysis.

2. Estimation strategy and data

2.1 Estimation strategy

To identify the causal impact of the LCR on the demand for reserves in the euro area, we exploit the harmonisation of the regulatory treatment of reserves for the purposes of fulfilling the LCR in the euro area as a quasi-natural experiment. Under the CRR, published in 2013, central bank reserves constitute HQLA for LCR purposes "to the extent that these exposures can be withdrawn at any time in times of stress".[5] The CRR also stipulates that a "common understanding regarding the extent to which minimum reserves can be withdrawn in times of stress" should be reached between the competent authority and central bank. In July 2015, the German Federal Financial Supervisory Authority (henceforth "German regulator") pre-announced that such a common understanding had been agreed for the Eurosystem,[6] although the formal announcement of this decision was only published by the

[5] CRR, Article 416, 1a.
[6] See the press release of the German Federal Financial Supervisory Authority entitled „Merkblatt zur Behandlung der Zentralbankreserven in der LCR", 27 July 2015, available at: <https://www.bafin.de/SharedDocs/Veroeffentlichungen/DE/Merkblatt/BA/mb_150722_Mindestreserve_LCR_ba.html>.

SSM on 30 September 2015.[7] Since the minimum LCR requirement came into effect on 1 October 2015, withdrawable reserves on day t are defined as the maximum of zero or the difference between the actual balances on reserve accounts on day t and the average daily required reserves for the respective maintenance period:

$$\textit{Withdrawable reserves}_t = \max\ (\textit{Actual balances on reserve accounts}_t - \textit{Average daily required reserves over maintenance period, 0}).$$

Prior to this point in time, the CRR was interpreted at the national level. The Eurosystem conducted an internal survey of euro area NCBs in the middle of 2014 to gather information on the way reserves were treated by national supervisors in the calculation of the LCR numerator and denominator.[8] According to the survey, six countries classified all central bank reserves as HQLA while twelve considered only reserves in excess of minimum reserve requirements as HQLA, thereby giving rise to differences in the treatment of reserves in the LCR numerator. With respect to the LCR denominator, eight countries considered reserve requirements as an outflow. Using the survey information, we identify two groups of countries based on the impact of the harmonisation of treatment on the marginal value of a unit of excess liquidity.[9] For one group, the marginal value increased and for the other group, it remained unchanged.

This information allows us to undertake a quasi-natural experiment given that there is no self-selection into the groups, which was determined by legal residence: banks in the group of countries for which the harmonised treatment increased the marginal regulatory value of excess liquidity constitute a "treatment group" (Austria, Belgium, Cyprus, Finland, France, Germany, Luxembourg and Italy) while those located in countries for which the common treatment left the marginal regulatory value of excess liquidity unchanged are a "control group" (Estonia, Ireland, Latvia, Malta, Netherlands, Portugal, Spain, Slovakia and Slovenia).[10] Owing to data considerations[11] and the supervisory

[7] See the ECB letter to banks entitled "Communication on the Treatment of central bank reserves with regard to the Liquidity Coverage Ratio (LCR)", 30 September 2015, available at: <https://www.bankingsupervision.europa.eu/press/letterstobanks/shared/pdf/2015/150930/150930communication_LCR_treatment_of_central_bank_reserves_for_LSIs.en.pdf?377e7b5daeb653f8d6ce1d580883f737>.

[8] To our knowledge, only Ireland published information on how it was treating central bank reserves for LCR purposes prior to the harmonisation of treatment. See Central Bank of Ireland (2014).

[9] "Excess liquidity" is the sum of "excess reserves" (which are reserves in excess of minimum reserve requirements held in banks' current accounts at their respective national central bank) and reserves held in the deposit facility.

[10] We exclude Greece from our analysis because the country introduced capital controls in June 2015. The timing of the introduction of capital controls overlaps with the German announcement of the common treatment of reserves and could therefore distort the interpretation of our results.

[11] Collection of LCR data at individual level only began in September 2016 when the LCR became part of the Implementing Technical Standards on Supervisory Reporting. Prior to this point in time, LCR data were collected as part of the Short Term Exercise (STE)

exemption of several banks at individual level from compliance with the LCR, our analysis is conducted at the consolidated banking group level.[12] The classification into treatment and control groups is therefore based on the location of the consolidated entity's parent.[13]

Akin to other empirical studies on the impact of regulation, such as Banerjee and Mio (2018), Fuhrer et al. (2017) and Rezende et al. (2016), we use DiD estimation techniques to compare reserve accumulation in the two groups after the pre-announcement of the harmonised treatment by the German regulator in July 2015. We use the pre-announcement as the start of the treatment period rather than the formal SSM announcement or the start of the harmonised regulatory regime because financial markets are forward-looking and react immediately to news. The treatment period therefore begins in 2015Q3.[14] Our testable hypothesis is that excess liquidity holdings of banks located in the treatment group in the treatment period increased by more than in the control group.

Although the LCR regulation has only been phased-in since 1 October 2015, with an initial minimum requirement set at 60%, it is well-documented that banks were widely front-loading their compliance with regulatory ratios. As of 30 June 2015, for example, 79% of the banks included in the European Banking Authority's CRR/Basel III monitoring exercise had an LCR above 100% (EBA, 2016). As shown in Table 1, the median LCR for banks in the control and treatment groups in our sample – which consists of 86 significant euro area banking groups supervised by the SSM – at the end of 2015Q2 was 158% and 144%, respectively. Front-loading does not violate the common-trend assumptions implicit in our DiD setting as banks in both the treatment and control groups were already in the process of building liquidity buffers. A change in the treatment of reserves would thus still be expected to induce a change in the behaviour of treated banks. Our identification of the effect of the LCR therefore rests on the assumption that the choice of the pre-harmonisation regime was not systematically related to differences in demand for central bank reserves.

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under the Supervisory Review and Evaluation Process. This data collection exercise included only systemically important institutions and reporting was at the highest level of consolidation.

[12] While banks can be granted a waiver from meeting the LCR requirements at individual level, they must comply with the regulation at consolidated level.

[13] The analysis therefore rests on the assumption that supervisory treatment of a consolidated entity for LCR purposes is determined by the rules in place in the location of the parent of the consolidated entity.

[14] Our dataset is constructed around end-of-quarter supervisory statistics (see Section 2.2). The pre-announcement by the German regulator in July 2015 should therefore affect banks' behaviour already in 2015Q3. The formal announcement by the SSM on 30 September 2015 coincides with the end-of-quarter regulatory reporting date. A change in banks' behaviour in response to the formal announcement would therefore only be expected to materialise from 2015Q4. Our results are robust to changing the treatment period from the date of the pre-announcement by the German regulator to the date of the formal announcement by the SSM (see Section 3.3).

We formally test the hypothesis following equation (1):

$$EL_{ijt} = \alpha + \beta(TREAT_j \times POST_t) + \mu \boldsymbol{X}_{it} + \eta Z_{jt} + \gamma_i + \vartheta_t + \varepsilon_{it} \quad (1)$$

where EL_{ijt} is the absolute level of excess liquidity holdings of bank *i,* located in country *j*, in quarter *t*. $TREAT_j$ is a dummy variable equal to 1 if the bank is located in a treatment group country and 0 if it is in a control group country. $POST_t$ is a dummy variable equal to 1 in the period following the German announcement of the common treatment of reserves and 0 before. Bank fixed effects and time fixed effects are denoted by γ_i and ϑ_t, respectively, and are included to control for time-invariant bank characteristics (e.g. business models) and factors that simultaneously affect all banks in the sample (e.g. the expansion of the asset purchase programme (APP) or global financial market developments).

$\boldsymbol{X}_{it}$ includes bank-level variables to control for liquidity injections to individual banks arising during the implementation of the APP, bank size and leverage ratios lagged by one period. Given the overlap between the exogenous provision of reserves to the banking system via the APP and the harmonisation of the LCR regulation, it is important to control for the supply-driven increase in reserves in order to isolate a demand-driven increase during the treatment period.[15] A higher accumulation of reserves owing to APP implementation is expected to be associated with higher excess liquidity holdings. Similarly, larger banks may accumulate more reserves than smaller banks. The leverage ratio is also likely to be positively correlated with excess liquidity because it imposes balance sheet costs on central bank reserves and may therefore act to reduce reserve accumulation to the extent that it binds or is low relative to peers.[16] We lag the leverage ratio by one period to account for possible endogeneity between excess liquidity and leverage ratios at time *t*. Z_{jt} is a control variable for the opportunity cost of reserves, which varies by country, and is included to account for the possibility that banks in countries with higher-yielding alternative HQLA might have less incentive to hold reserves.[17] The construction of these variables is explained in Section 2.2.

[15] The aggregate amount of reserves created under the APP is exogenous to the banking system. At the individual bank level, reserves received as a result of intermediating APP transactions on behalf of another underlying seller are also exogenous to the bank. However, a bank can use the APP to acquire reserves by selling its own securities holdings to the Eurosystem.

[16] The leverage ratio is a non-risk based capital requirement aimed at constraining excessive leverage in the banking system. It is calculated as Tier 1 capital over a banks' total exposures measure, which consists of both on and off-balance sheet items. For further discussion of the leverage ratio, see Grill et al. (2015) and BIS Committee on the Global Financial System (2015).

[17] In countries where sovereign yields are above the rate on the ECB's deposit facility, banks may prefer to hold HQLA in the form of government bonds rather than reserves. In countries where short-term government bond yields are below the ECB's deposit facility rate, banks may prefer to hold HQLA in the form of reserves. For further discussion, see Baldo et al. (2017).

As the LCR may only affect behaviour when it binds or nearly binds, or if a bank's LCR is low relative to its peers, we also employ a triple differences model to assess the impact of the LCR regulation on reserve demand conditional on the degree of compliance with the LCR requirement just before the harmonisation announcement, following equation (2):

$$EL_{ijt} = \alpha + \beta_1(TREAT_j \times POST_t) + \beta_2(TREAT_j \times LCR_i) + \beta_3(POST_t \times LCR_i) + \beta_4(TREAT_j \times POST_t \times LCR_i) + \mu \boldsymbol{X}_{it} + \eta Z_{jt} + \gamma_i + \vartheta_t + \varepsilon_{it}$$

(2)

An LCR of 130% is used as a threshold level to denote a relatively low LCR because it is the level that encompasses the lower quartiles of both the treatment and control groups (Table 1). Hence, a level of 130% is consistent with the need to identify low-LCR banks in our sample while at the same time retaining a sufficient number of low-LCR banks in both the treatment and control groups. Although 130% is well-above the minimum fully phased-in requirement of 100%, banks have a long history of holding regulatory buffers. This phenomenon has been attributed in the literature to the effectiveness of market discipline (Fonseca and González, 2014; Flannery and Rangan, 2008; and Nier and Baumann, 2006), as well as to banks' desire to reduce the likelihood of non-compliance (Berger et al., 2008) and to signal their strength relative to peers (Lindquist, 2004 and Baldo et al., 2018). Hence, the LCR can be viewed as effectively binding at levels higher than the minimum requirement (Bonner and Eijffinger, 2016), which further supports the use of an LCR threshold above 100%.

We compute bootstrap standard errors clustered at the country level. This follows the suggestion of Bertrand et al. (2004) to address the inconsistency of standard errors in DiD estimation that can arise from serially correlated outcomes in multi-period samples. In robustness tests, we collapse the sample into two periods, which is another approach proposed by Bertrand et al. (2004) to deal with inconsistency. In other robustness checks, we consider alternative standard errors, shorten the time window around the treatment period, shift back the start of the treatment period to align it with the formal announcement of the harmonised treatment by the SSM (i.e. treatment beginning in 2015Q4 rather than 2015Q3), fictionally shift forward the treatment period by one quarter (i.e. treatment beginning in 2015Q2 rather than 2015Q3) in a "placebo regression", restrict the sample to the banks located only in non-core countries and include country fixed effects. We also perform DiD estimation using equation 1 on the sub-sample of low-LCR banks to compare excess liquidity accumulation between low-LCR banks in the treatment and control countries.

2.2 Data

Our analysis is based on a unique and proprietary dataset available at the ECB. We construct a panel of quarterly banking group level data from 2014Q1 to 2016Q4 that combines information from a number of sources. LCRs are obtained from quarterly supervisory data collection exercises starting from 2014Q4. The supervisory dataset consists of significant supervised euro area banks as defined in the SSM Framework Regulation.[18] These statistics are reported at the highest level of consolidation in the SSM statistics.[19] To avoid that compositional changes in the panel influence our results, we use a balanced panel that includes the 86 banking groups which reported an LCR in 2015Q2, the last quarter of the pre-treatment period.[20] Data on banks' leverage ratios are also obtained from the supervisory statistics.

Reserve holdings are retrieved from the internal Eurosystem market operations database and are measured in millions of euro. Excess liquidity at the bank level is calculated as the sum of a bank's current account balance with the central bank and use of the deposit facility, less its minimum reserve requirement. As the market operations database is at the level of ECB monetary financial institutions (MFIs) while LCR data are reported in supervisory statistics at the consolidated level using Legal Entity Identifiers (LEIs), we identify the list of individual MFIs that are subsumed in each supervised group's LEI over time using the Register of Institutions and Affiliates Database (RIAD). MFI holdings of excess liquidity are then aggregated to reflect consolidated figures and are averaged over the quarter.[21]

Our control variable for the supply-driven increase in reserve holdings reflects the cumulated flows of reserves to banks arising during the implementation of the APP. The variable is constructed by combining transaction-level APP data with information from the TARGET2 payments system in order to identify the TARGET2 participant through which an APP counterparty transacts in central bank money. As discussed in Eisenschmidt et al. (2017), this is generally the APP counterparty itself if it is located in the euro area. For APP counterparties located outside of the euro area, payments in

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[18] Regulation (EU) No 468/2014.

[19] For more details on supervisory banking statistics, see the ECB's methodological note available at: <https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm.methodologicalnote_supervisorybankingstatistics201710.en.pdf>.

[20] As our analysis requires classification of banks into high- and low-LCR groups, the banking groups that did not report an LCR in 2015Q2 are excluded from the sample.

[21] The use of quarterly average excess liquidity figures rather than end-of-quarter figures derives from the fact that banks have to meet the LCR on a daily basis, rather than only at the end of the quarter (or end of the month), and excess liquidity is a maintenance period concept rather than a point-in-time concept owing to minimum reserve averaging in the euro area. Hence, excess liquidity cannot be precisely calculated for any given day and it is therefore preferable to consider average data over a longer time period. Our results are robust to using end-of-quarter data instead of quarterly averages and are hence robust to potential end-of-month window-dressing behaviour by banks aimed at increasing LCR levels.

TARGET2 can be received via a euro area branch or via a euro area correspondent bank. As a measure of banks' opportunity cost of holding reserves relative to other forms of short-duration HQLA, we also include in the dataset the average quarterly spread between sovereign bonds with a one-year maturity and the deposit facility rate.

Table 1 summarises the distribution of the variables for banks in the control and treatment groups in 2015Q2. The mean levels of excess liquidity (measured in millions of euro) and bank size (measured in terms of minimum reserve requirements, in millions of euro) were almost the same across both groups of banks. Banks in the control group had a higher average leverage ratio than banks in the treatment group while they had a lower mean level of APP liquidity (in millions of euro) than banks in the treatment group; the differences in these variables between the groups are not statistically significant. The average opportunity cost of holding reserves relative to short-term domestic sovereign bonds (measured in basis points) was significantly higher in the control group, reflecting differences in the country composition of the two groups, as was the mean LCR.

Table 2 compares the distribution of variables for banks with high and low LCRs in 2015Q2. There was no statistically significant difference between the means of excess liquidity, the opportunity cost of reserves, leverage ratios or bank size in high- versus low-LCR banks. However, low-LCR banks had significantly more APP liquidity on average in 2015Q2 than high-LCR banks. This underscores the need to control for APP liquidity injections in our analysis.

Reflecting liquidity injections via targeted longer-term refinancing operations and the APP from late 2014 onwards, excess liquidity increased notably by 2016Q4 for banks in both the control and treatment groups (Figure 1), as well as in both the high- and low-LCR groups (Figure 2). Focusing on the subset of banks with low LCRs, there was a sharp increase in average excess liquidity holdings in the treatment group from 2015Q2 onwards (Figure 3). Within the treatment group, there were also pronounced differences in average excess liquidity holdings between low- and high-LCR banks from 2015Q2 onwards, with low-LCR banks increasing their excess liquidity holdings more sharply than high-LCR banks (Figure 4). Figures 1 to 4 broadly confirm the pre-treatment parallel trends assumption underlying DiD estimation.

Given the coincidence in timing between the pre-announcement by the German regulator and the notable expansion of the APP following the commencement of the Public Sector Purchase Programme (PSPP), which could be driving excess liquidity developments, we also visually inspect average excess liquidity purged of the estimated impact of the implementation of the APP. The purged data confirm diverging trends for low- and high-LCR banks in the treatment group from 2015Q2 (Figure A.1 in Annex).[22]

Table 1: Distribution of key variables – banks located in control and treatment countries (2015Q2)

Banks in control group countries: 29					
			percentile		
	Mean	SD	75th	50th	25th
Excess liquidity (EUR mn)	1252.4	4283.4	590.3	83.9	5.6
LCR (%)	244.0	191.0	236.4	158.3	132.3
APP liquidity (EUR mn)	921.4	2596.1	117.4	1.8	0.0
Opportunity cost of reserves (bps)	16.6	9.8	22.3	22.3	11.3
Leverage ratio (%, lagged)	7.0	3.4	7.4	6.0	4.9
Minimum reserve requirement (EUR mn)	682.0	1354.0	438.7	255.9	71.8
Banks in treatment group countries: 57					
			percentile		
	Mean	SD	75th	50th	25th
Excess liquidity (EUR mn)	1231.7	2603.0	1420.4	164.7	8.6
LCR (%)	162.5	98.9	173.8	144.2	107.7
APP liquidity (EUR mn)	1451.4	3995.0	416.8	0.0	0.0
Opportunity cost of reserves (bps)	4.4	12.3	4.1	0.9	-6.7
Leverage ratio (%, lagged)	6.0	3.3	7.3	5.0	4.0
Minimum reserve requirement (EUR mn)	646.4	1046.4	667.5	263.1	131.5

[22] Excess liquidity purged of the impact of the implementation of the APP is calculated by regressing bank-level excess liquidity on the stock of reserves that would be accumulated by banks during APP implementation, ceteris paribus, and banks' minimum reserve requirements (as a proxy for bank size), as well as bank and time fixed effects. Purged excess liquidity is then computed as the difference between a bank's actual excess liquidity and the cumulated amount of APP liquidity flowing to that bank during the implementation of asset purchases multiplied by the respective coefficient estimate.

Table 2: Distribution of key variables – high- and low-LCR banks (2015Q2)

Banks with high LCRs: 58					
			percentile		
	Mean	SD	75th	50th	25th
Excess liquidity (EUR mn)	1187.6	3224.5	904.0	145.3	8.6
LCR (%)	234.0	153.3	230.7	171.8	151.6
APP liquidity (EUR mn)	627.5	1796.8	168.5	0.0	0.0
Opportunity cost of reserves (bps)	8.0	13.2	22.3	0.9	-4.8
Leverage ratio (%, lagged)	6.6	3.8	7.4	5.1	4.5
Minimum reserve requirement (EUR mn)	551.9	1071.1	415.5	215.6	65.3

Banks with low LCRs: 28					
			percentile		
	Mean	SD	75th	50th	25th
Excess liquidity (EUR mn)	1344.5	3333.6	1065.3	82.3	2.0
LCR (%)	98.7	20.5	113.4	102.7	89.7
APP liquidity (EUR mn)	2609.0	5543.5	2020.6	53.3	0.0
Opportunity cost of reserves (bps)	7.8	12.5	22.3	4.1	-3.0
Leverage ratio (%, lagged)	5.9	2.3	7.1	5.6	4.2
Minimum reserve requirement (EUR mn)	878.9	1294.6	797.3	394.3	199.3

Figure 1: Quarterly average excess liquidity in treatment and control groups *(€ mn)*

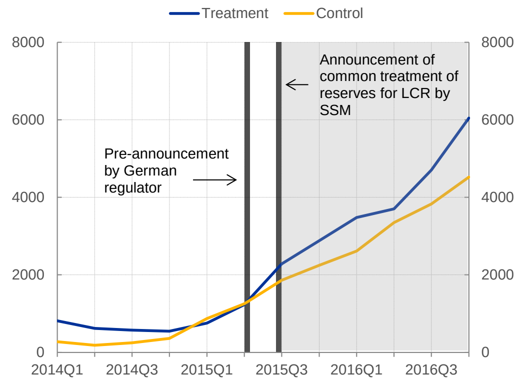


Figure 2: Quarterly average excess liquidity of banks with low and high LCRs as of 2015Q2 *(€ mn)*

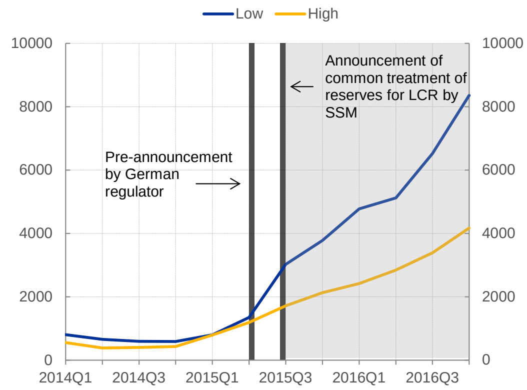


Figure 3: Quarterly average excess liquidity in treatment and control groups for banks with low LCRs as of 2015Q2 *(€ mn)*

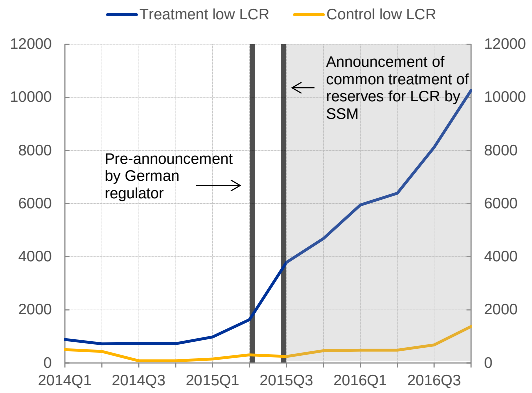
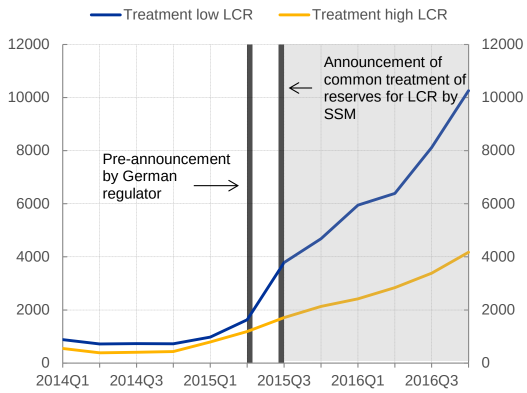


Figure 4: Quarterly average excess liquidity in treatment group for banks with low versus high LCRs as of 2015Q2 *(€ mn)*



Notes: The shaded region shows the period during which the minimum LCR requirements were phased in. The formal announcement of a common treatment of central bank reserves for the purposes of the LCR in the euro area was published on 30 September 2015 by the SSM. The German regulator pre-announced the common treatment in July 2015.

3. Results

3.1 Effect of the LCR regulation independent of the degree of compliance

Estimation results for equation (1) are shown in Table 3. Beginning with the traditional DiD specification, which includes no control variables, we obtain a coefficient estimate for our DiD term (*Treat x Post*) that is not significant (column 1). Additional control variables are added to the regression in columns 2-5. In line with our expectations, the coefficient of the APP liquidity control variable is positive, as well as highly significant. However, the DiD term is not significant across any of the variations of equation 1. The null hypothesis that there is no effect of the preferential change in treatment of reserves for the purposes of fulfilling the LCR on the demand for excess liquidity is therefore not rejected. This finding provides empirical support to the notion that the effects of liquidity regulation on banks' behaviour are limited or non-existent if banks have a surplus of liquid assets (Bech and Keister, 2015 and Duffie and Krishnamurthy, 2016).

Table 3: Estimated impact of the LCR on the demand for excess liquidity (equation 1)

$Y = EL_{it}$	(1)	(2)	(3)	(4)	(5)
Treat x Post	554.9 (2413.9)	-545.4 (2617.4)	-999.1 (3315.3)	-452.6 (2599.1)	-1153.8 (2535.0)
APP		0.502* (0.282)	0.501* (0.283)	0.374*** (0.133)	0.488*** (0.089)
Opportunity cost of reserves			-36.14 (26.30)	-51.10* (27.75)	-129.8** (55.25)
Bank size				16.45** (7.931)	8.104 (10.378)
Leverage ratio (one period lag)					-7408.6 (42334.6)
Constant	633.4*** (162.8)	633.4*** (152.6)	1924.7** (951.8)	-8849.8* (5331.5)	-2689.0 (9186.9)
Bank fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	1032	1032	900	900	590
Banks	86	86	75	75	75
Within R-squared	0.116	0.576	0.579	0.637	0.664

*Notes: Country-clustered bootstrap standard errors in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels. Significance levels remain broadly unchanged with country-clustered robust standard errors. The pre-treatment period runs from 2014Q1 to 2015Q2. The post-treatment period runs from 2015Q3 to 2016Q4. As no benchmark one-year sovereign bond yields are available for Cyprus, Estonia, Latvia, Luxembourg and Slovakia, banks located in these countries drop out of the sample when controlling for the opportunity cost of reserves. Full regression output is available upon request.*

3.2 *Effect of the LCR regulation conditional on the degree of compliance*

Table 4 presents the baseline estimation results of equation 2. In contrast to the results of the DiD estimation, the triple differences estimation suggests that there is LCR-induced demand for reserves amongst banks with LCRs that are low relative to other systemically important banks. This finding supports the hypothesis that liquidity regulation can affect banks' behaviour when it is binding or when the degree of (over-)compliance is low relative to one's peer group. Excluding control variables, the change in excess liquidity between low- and high-LCR banks in the treatment group *(Treat x Post x LCR)* is around €6.8 billion higher on average than the change between low- and high-LCR banks in the control group over the six quarters following the harmonisation announcement (column 1). Although the inclusion of control variables reduces the magnitude of the estimated impact of the LCR on demand for reserves, the impact remains statistically significant and substantial, with a minimum value of €4.7 billion (column 5). Multiplying the average effect for the treated banks in our sample by the number of low-LCR banks in the treatment group (22) indicates an aggregate increase in excess liquidity holdings owing to the LCR of between €103 billion and €150 billion. As our sample of significant supervised euro area banks represents around 70% of total banking sector assets in 2015Q2, the results can be considered a lower-bound estimate of the impact of the LCR regulation on demand for reserves in the euro area. Assuming that our results for the sample of significant institutions supervised by the SSM are representative of the entire euro area banking sector, they imply a total LCR impact on reserve demand of between €148 billion and €214 billion.

The control variables have the expected sign but vary in significance. Focusing on the results presented in column 4, in which all of the control variables are significant, a €10 million increase in the cumulative amount of a bank's APP liquidity is associated with excess liquidity values that are higher on average by €3.8 million. Bank size is also positively correlated with excess liquidity holdings: a €10 million increase in a bank's minimum reserve requirement increases excess liquidity by €159.2 million. A one basis point increase in the opportunity cost of holding reserves is associated with excess liquidity that is lower by €48.3 million.

Table 4: Estimated impact of the LCR on the demand for excess liquidity conditional on the LCR being below 130% in 2015Q2 (equation 2)

$Y = EL_{it}$	(1)	(2)	(3)	(4)	(5)
Treat x Post x LCR	6803.9** (3268.5)	4817.6** (2480.0)	5712.6* (3239.2)	4873.5* (2588.3)	4699.6** (2203.2)
APP		0.503*** (0.108)	0.500*** (0.084)	0.378*** (0.099)	0.485*** (0.135)
Opportunity cost of reserves			-33.36 (24.09)	-48.26* (28.85)	-128.0** (52.48)
Bank size				15.92*** (5.668)	8.31 (9.366)
Leverage ratio (one period lag)					-3674.2 (35575.0)
Constant	633.4*** (142.1)	633.4*** (126.1)	1830.5** (938.9)	-8578.4* (4637.5)	-3077.2 (7380.0)
Simple interaction terms	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	1032	1032	900	900	590
Banks	86	86	75	75	75
Within R-squared	0.148	0.587	0.593	0.647	0.672

*Notes: Country-clustered bootstrap standard errors in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels. Significance levels remain broadly unchanged with country-clustered robust standard errors. The pre-treatment period runs from 2014Q1 to 2015Q2. The post-treatment period runs from 2015Q3 to 2016Q4. As no benchmark one-year sovereign bond yields are available for Cyprus, Estonia, Latvia, Luxembourg and Slovakia, banks located in these countries drop out of the sample when controlling for the opportunity cost of reserves. Full regression output is available upon request.*

3.3 Robustness tests

We perform a number of robustness tests to verify the results of our baseline triple differences model. Replacing the country-clustered bootstrap standard errors with country-clustered robust standard errors does not change the statistical significance. Moreover, the results are robust to collapsing the sample into two periods: one pre-treatment period averaging the variables across the six quarters up to and including 2015Q2 and one post-treatment period averaging the variables for the six quarters up to and including 2016Q4. Based on this collapsed sample, the change in excess liquidity between low- and high-LCR banks in the treatment group is between €4.1 billion to €6.8 billion larger on average than the change between low- and high-LCR banks in the control group after the harmonisation announcement (Table A.1).

The results are also robust to shortening the treatment window to between one and five quarters on either side of the harmonisation announcement. The results of the regression focusing on one quarter before and one quarter after the harmonisation announcement are shown in Table A.2. In this specification, the change in excess liquidity between low- and high-LCR banks in the treatment group is between €1.4 billion and €2.6 billion larger than the respective change in the control group. This translates into aggregate regulatory demand for reserves in our sample of between €32 billion and €58 billion. For the euro area banking sector as a whole, the results imply an increase in demand for reserves of between €46 billion and €83 billion, assuming that our sample of significant institutions – which covers 70% of banking sector assets in 2015Q2 – is representative of dynamics across the entire banking system.

Artificially shifting the treatment date forward by one quarter from 2015Q3 to 2015Q2 and comparing changes in excess liquidity between low- and high-LCR banks in the treatment and control groups from 2015Q1 (one-quarter pre-treatment period) to 2015Q2 (one-quarter placebo post-treatment period) indicates no statistically significant difference (Table A.3). The results of this one-quarter window placebo regression confirm that the divergence in excess liquidity holdings between the groups only began following the pre-announcement of a harmonisation of the treatment of reserves for LCR purposes by the German regulator. In addition, the results of the baseline analysis are robust to taking the formal announcement of the harmonised treatment by the SSM as the start of the treatment period (i.e. starting the treatment period in 2015Q4 rather than 2015Q3).

Restricting the sample to banks located in non-core countries also supports the conclusion that excess liquidity accumulation was greater for low-LCR banks relative to high-LCR banks in the treated group compared with the control group following the harmonisation announcement.[23] The results are also robust to including country fixed effects. Finally, we also compare reserve accumulation between low-LCR banks in the treatment group with low-LCR banks in the control group by estimating equation (1) on the sub-sample of low-LCR banks. The results of this DiD estimation confirm the conclusions drawn from our baseline triple differences estimation: banks with low LCRs in the treatment group countries

[23] The countries included in the non-core group are Cyprus, Italy, Portugal, Slovenia and Spain.

accumulated more excess liquidity than banks with low LCRs in the control group countries following the harmonisation announcement (Table A.4).[24]

However, when reducing the LCR threshold to 120%, the results of the baseline regression are only robust when control variables are excluded, indicating the importance for the analysis of retaining all banks with LCRs in the lowest quartile of the sample distribution.

4. Policy implications and conclusion

Our results indicate that the LCR might increase demand for central bank reserves amongst banks with low liquidity buffers relative to peers. These findings have important implications for monetary policy in the euro area and suggest that the Eurosystem's operational framework needs to remain sufficiently flexible to respond to changes over time in the regulatory demand for reserves. These findings are particularly relevant in the context of the monetary policy strategy review of the ECB.

According to our baseline analysis, additional demand for reserves in the euro area owing to liquidity regulation ranged between €103 billion and €150 billion on average for our sample over the period from 2015Q3 to 2016Q4, and is estimated to range between €148 billion and €214 billion for the euro area banking sector as a whole.[25] This is substantial when compared with the pre-crisis liquidity deficit of circa €450 billion, which was the basis for calibrating the supply of reserves to the banking system. Not accommodating this additional demand for reserves could therefore result in notable upward pressure on money market rates.

Specifically, a return to the pre-crisis implementation modalities, under which monetary policy operations were conducted as variable-rate tender procedures with an allotment amount that just satisfied the liquidity deficit, as determined by reserve requirements and the set of pre-crisis autonomous factors (i.e. without regard for LCR-related reserve demand), may be associated with volatility in money market rates, more aggressive bidding behaviour in open market operations and an increase in key short-term market reference rates, like the EONIA. A de-anchoring of the EONIA from the key ECB interest rates, in turn, has implications for the transmission of the intended monetary

[24] In this specification, the increase in excess liquidity of low-LCR banks in treatment group countries was between €2.5 billion and €5.2 billion larger on average than the change in excess liquidity of low-LCR banks in control group countries. The sample size underlying this DiD regression is limited: 22 banks in our sample are low-LCR banks located in treatment group countries and only 6 banks are low-LCR banks located in control group countries.

[25] Assuming that our results for the sample of significant institutions supervised by the SSM are representative of the entire euro area banking sector and can therefore be scaled up.

policy stance to market- and bank-based funding costs because the EONIA is the basis of the overnight indexed swap (OIS) curve, which is the reference curve used to price many financial instruments in the euro area. OIS rates also directly affect Euro Interbank Offered Rates (Euribor),[26] which are widely used in the pricing of bank loans in the euro area.

One solution to preserve the controllability of short-term interest rates, and thereby to safeguard the smooth implementation and transmission of monetary policy, is for the Eurosystem to supply additional reserves to the banking sector. In other words, regulatory demand for reserves could be treated as a new autonomous factor that is subject to forecasting.[27] This implies that the Eurosystem's balance sheet could remain structurally larger than it was prior to the financial crisis and the associated introduction of new liquidity regulation.

However, calibrating the additional supply of reserves with enough precision to steer short-term interest rates in a narrow range around the key policy rates could prove to be very challenging. This is because LCR-related demand for reserves is likely to vary over time. For example, regulatory demand for reserves could be higher when market interest rates are rising, such as during a policy tightening cycle or during periods of stress, because rising interest rates reduce the marketable value of securities that qualify as HQLA. On the other hand, the magnitude of LCR-related demand for reserves could move inversely with the opportunity costs of holding reserves relative to other HQLA. In a steady-state, when banks fully comply with the LCR and hold ample liquidity buffers, it is not clear that LCR-related demand for reserves would emerge to a degree that hampers monetary policy implementation.

An alternative solution aimed at fostering short-term interest rate control is for the Eurosystem to retain fixed-rate tender procedures with full allotment. This option provides flexibility to satisfy all demand for reserves at the policy rate, subject to collateral constraints, and therefore does not depend on accurate forecasts of demand arising from liquidity regulation.

To conclude, retaining at least some of the changes in the Eurosystem's operational framework introduced since the financial crisis could be a means of ensuring sufficient flexibility to respond to regulatory demand for central bank reserves in the future, thereby preserving the ECB's ability to steer

[26] Euribor can be decomposed into a risk-free component (approximated by the OIS rate) and risk premia. See for example Eisenschmidt and Tapking (2009), Schwarz (2019) and Taylor and Williams (2009).
[27] For further discussion of liquidity forecasting, see ECB (2014).

short-term interest rates in line with the intended monetary stance and safeguard the smooth implementation and transmission of monetary policy.

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Annex

Table A.1: Collapsed two-period sample – estimated impact of the LCR on the demand for excess liquidity conditional on the LCR being below 130% in 2015Q2 (equation 2)

$Y = EL_{it}$	(1)	(2)	(3)	(4)	(5)
Treat x Post x LCR	6803.9** (3271.1)	4799.4* (2631.7)	5416.0 (3087.7)	4111.1* (2222.7)	4552.8* (2251.4)
APP		0.508*** (0.075)	0.507*** (0.075)	0.227*** (0.078)	0.205** (0.078)
Opportunity cost of reserves			-204.75 (294.1)	-153.4 (150.2)	-159.6 (146.4)
Bank size				30.94*** (7.00)	32.8*** (6.28)
Leverage ratio (one period lag)					63447.2 (48934.3)
Constant	681.35 (503.6)	520.61 (431.6)	5327.9 (5720.4)	-17593.6** (6175.5)	-22569.0*** (5858.2)
Simple interaction terms	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	172	172	150	150	148
Banks	86	86	75	75	75
Within R-squared	0.168	0.607	0.620	0.733	0.741

*Notes: Country-clustered robust standard errors in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels. The regression consists of one pre-treatment period (reflecting averages between 2014Q1 and 2015Q2) and one post-treatment period (reflecting averages between 2015Q3 and 2016Q4). As no benchmark one-year sovereign bond yields are available for Cyprus, Estonia, Latvia, Luxembourg and Slovakia, banks located in these countries drop out of the sample when controlling for the opportunity cost of reserves. Full regression output is available upon request.*

Table A.2: One-quarter window – estimated impact of the LCR on the demand for excess liquidity conditional on the LCR being below 130% in 2015Q2 (equation 2)

$Y = EL_{it}$	(1)	(2)	(3)	(4)	(5)
Treat x Post x LCR	2636.4**	1828.0**	1448.0*	1481.0*	1693.6**
	(1073.9)	(834.1)	(728.4)	(697.0)	(766.5)
APP		0.978***	0.951***	0.867***	0.814***
		(0.178)	(0.190)	(0.192)	(0.251)
Opportunity cost of reserves			-195.0	-199.4	-217.6
			(163.6)	(166.1)	(164.8)
Bank size				8.57	12.44
				(13.4)	(19.7)
Leverage ratio (one period lag)					28423.6
					(28450.4)
Constant	1238.7***	-6.2	1466.8	-4754.0	-9191.9
	(163.8)	(316.7)	(1370.2)	(10227.7)	(15364.3)
Simple interaction terms	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	172	172	150	150	146
Banks	86	86	75	75	73
Within R-squared	0.159	0.627	0.645	0.651	0.655

*Notes: Country-clustered robust standard errors in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels. The regression consists of one pre- and one post-treatment period (i.e. 2015Q2 is the pre-treatment period and 2015Q3 is the post-treatment period). As no benchmark one-year sovereign bond yields are available for Cyprus, Estonia, Latvia, Luxembourg and Slovakia, banks located in these countries drop out of the sample when controlling for the opportunity cost of reserves. Full regression output is available upon request.*

Table A.3: One-quarter window placebo regression – estimated impact of the LCR on the demand for excess liquidity conditional on the LCR being below 130% in 2015Q2 (equation 2, 2015Q1 as "pre-treatment" and 2015Q2 as "post-treatment")

$Y = EL_{it}$	(1)	(2)	(3)	(4)	(5)
Treat x Post x LCR	559.9	454.4	473.6	-203.2	-70.0
	(444.6)	(376.9)	(336.2)	(197.3)	(185.0)
APP		0.190	0.185	-0.051	-0.054
		(0.112)	(0.114)	(0.076)	(0.076)
Opportunity cost of reserves			104.2*	42.78	40.89
			(119.8)	(37.38)	(37.94)
Bank size				12.97***	12.84***
				(1.92)	(1.83)
Leverage ratio (one period lag)					-22452.9*
					(-22452.9)
Constant	794.7***	701.9***	-1000.2	-9106.3***	-7960.3***
	(79.7)	(129.7)	(931.3)	(1474.4)	(1626.0)
Simple interaction terms	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	172	172	150	150	146
Banks	86	86	75	75	73
Within R-squared	0.157	0.282	0.321	0.625	0.629

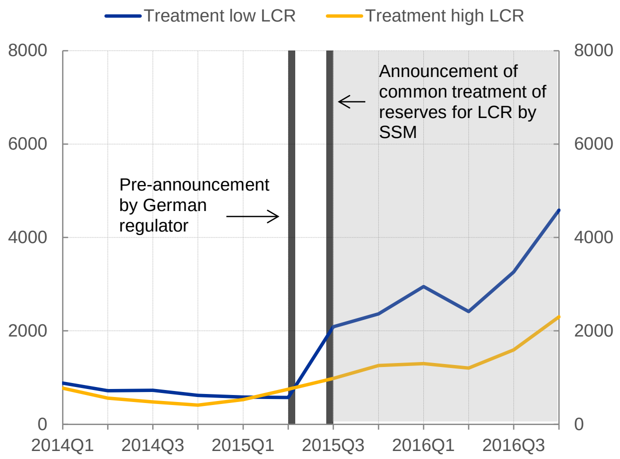
*Notes: Country-clustered robust standard errors in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels. The regression artificially shifts forward the treatment period by one quarter from 2015Q3 to 2015Q2 and compares reserve accumulation during a one-quarter window on either side of the artificial treatment date (i.e. between 2015Q1 (the placebo pre-treatment period) and 2015Q2 (the placebo post-treatment period)). As no benchmark one-year sovereign bond yields are available for Cyprus, Estonia, Latvia, Luxembourg and Slovakia, banks located in these countries drop out of the sample when controlling for the opportunity cost of reserves. Full regression output is available upon request.*

Table A.4: Estimated impact of the LCR on the demand for reserves – sub-sample of low-LCR banks (equation 1)

Y = EL_{it}	(1)	(2)	(3)	(4)	(5)
Treat x Post	5224.2** (2617.4)	3056.9* (1739.3)	2955.1* (1816.6)	2891.2 (2034.6)	2519.2* (1326.9)
APP		0.534*** (0.211)	0.533*** (0.154)	0.489** (0.212)	0.578 (0.372)
Opportunity cost of reserves			-28.88 (21.03)	-38.57* (22.14)	-32.83 (47.68)
Bank size				6.360 (7.11)	-3.050 (13.70)
Leverage ratio (one period lag)					43737.6 (67381.8)
Constant	801.7** (381.4)	801.7** (361.9)	1753.1** (830.3)	-3200.7 (4716.0)	1029.3 (11897.7)
Bank fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	336	336	324	324	213
Banks	28	28	27	27	27
Within R-squared	0.161	0.814	0.814	0.820	0.839

*Notes: Country-clustered bootstrap standard errors in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels. Significance levels remain broadly unchanged with country-clustered robust standard errors. The pre-treatment period runs from 2014Q1 to 2015Q2. The post-treatment period runs from 2015Q3 to 2016Q4. As no benchmark one-year sovereign bond yields are available for Cyprus, Estonia, Latvia, Luxembourg and Slovakia, banks located in these countries drop out of the sample when controlling for the opportunity cost of reserves. Full regression output is available upon request.*

Figure A.1: Quarterly average APP-purged excess liquidity in treatment group for banks with low versus high LCRs as of 2015Q2 (€ mn)



Notes: The shaded region shows the period during which the minimum LCR requirements were phased in. The formal announcement of a common treatment of central bank reserves for the purposes of the LCR in the euro area was announced on 30 September 2015 by the SSM. The German regulator pre-announced the common treatment in July 2015. Excess liquidity purged of the impact of the implementation of the APP is calculated by regressing bank-level excess liquidity on the stock of reserves that would be accumulated by banks during APP implementation, ceteris paribus, and banks' minimum reserve requirements (as a proxy for bank size), as well as bank and time fixed effects. Purged excess liquidity is then computed as the difference between a bank's actual excess liquidity and the cumulated amount of APP liquidity flowing to that bank during the implementation of asset purchases multiplied by the respective coefficient estimate.

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