Effects of Changing Monetary and Regulatory Policy on Money Markets*

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Abstract

The global financial crisis and the response of monetary and regulatory authorities led to substantial changes in overnight U.S. dollar funding markets, which are crucial for monetary policy transmission. We show that amid major changes in market structure, the federal funds rate continued to provide an anchor for unsecured rates, albeit weaker, while its transmission to the repo market has been hampered in the post-crisis period. The Federal Reserve's new reverse repurchase facility led to stronger co-movement as well as lower volatility of rates. Meanwhile, the new regulations affected market rates around financial reporting days through increased balance sheet costs.

Keywords: Overnight money markets, federal funds, repo, Eurodollar, commercial paper, ON RRP, VAR models, GARCH models.

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1 Introduction

Money markets provide short-term funding for the financial system where highly liquid instruments are traded by a wide range of participants. Trades in different segments of the money market are usually for maturities less than a year with bulk of the activity taking place overnight. Money markets also play a crucial role for monetary policy transmission. Central banks typically target an overnight interest rate as their policy rate, through which the transmission of monetary policy to the yield curve takes place. The first step of the transmission of monetary policy implemented by the Federal Reserve (Fed) is for the federal funds rate to influence dynamics of the other overnight interest rates. For effective implementation of the monetary policy, other rates should move closely with the federal funds rate, that is, after controlling for risk factors and market frictions, rate differentials should be arbitraged away.

The response of the Fed to the global financial crisis significantly altered the monetary policy implementation framework in the United States. With successive rate cuts, the federal funds rate target was reduced from 5.25 percent in August 2007 to its effective lower bound (ELB) of 0 to 0.25 percent in December 2008. The federal funds rate, as well as other overnight rates, remained at the ELB for the next seven years. Throughout the crisis and its aftermath, the Fed used a variety of new facilities to provide liquidity to the financial system as well as unconventional tools, such as large-scale asset purchases, to stimulate the economy. As a result, reserves in the banking system have reached unprecedented levels. Marking a significant shift in its policy framework, the Fed started paying interest on bank reserves (IOR) in October 2008 to achieve rate control in an environment of superabundant reserves.

The elevated reserves and the new monetary policy tools affected trading dynamics in the money markets. In the federal funds market, government-sponsored enterprises (GSEs) that are not eligible to earn IOR, became the primary lenders, while large and foreign banks borrowed funds at rates below IOR for arbitrage purposes. Mainly because of this fragmented market structure, the IOR could not set a lower bound on the federal funds rate, leading the Fed to introduce a supplementary tool, the overnight reverse repurchase (ON RRP) facility in September 2013 to enhance monetary control.

The changing regulatory environment also created new incentives for participants amid a substantial decline in the leverage of securities dealers. Among the new regulations, the change in the assessment base for the Federal Deposit Insurance Corporation (FDIC) deposit insurance and the Basel III leverage ratio requirement are of particular importance. The former made wholesale funding more costly for U.S. chartered banks relative to that of U.S. branches and agencies of foreign banks, creating an incentive for domestic banks to reduce their money-market borrowing. The latter incentivized foreign banks to dynamically deleverage through money market activity given regional differences in implementation of the leverage ratio. Meanwhile, both leverage levels and net repo liabilities of the broker-dealer sector decreased notably, creating an important contrast to the pre-crisis period during which such institutions largely operated outside of the regulated banking system.

In this paper, we analyze evolving dynamics of money markets against the backdrop of the aforementioned changes in the monetary and regulatory environment. We estimate systems of dynamic models for overnight funding rates for two major sample periods: first is the pre-crisis period that runs from January 2001 to 2007 and serves as a benchmark, and the second is from December 2008 to August 2015, over which the aforementioned changes took place. Because the federal funds rate had been near-zero over the latter sample, we will simply refer to it as the ELB sample. Our models incorporate the long-run relationship of the federal funds rate with the other overnight rates during the pre-crisis period and allow for potentially different dynamics around financial reporting days when some institutions withdraw from money markets to contract their balance sheets. We explicitly model time-variation in the volatilities and correlations of rates in a multivariate framework and quantify distinct effects of regulations around financial reporting days. We also focus on changes in market dynamics due to the inception of the ON RRP facility in September 2013. This date provides a natural structural breakpoint in the ELB sample, as it corresponds to the expansion of the Fed's monetary policy toolkit, as well as the announcement and implementation of Basel III regulations.

A key question in the context of monetary policy transmission is how, and to what extent, the pass-through from the federal funds rate to other money market interest rates has been affected over time. Our results show that despite important changes in the market structure, the federal funds rate continued to provide an anchor for unsecured overnight rates, although co-movement of rates has weakened. In particular, transmission to the repo rates from the federal funds rate has been hampered significantly.

We show that new regulations have substantially altered the dynamics of unsecured rates on financial-reporting days by increasing balance sheet costs of financial intermediaries. Specifically, rates that represent unsecured wholesale funding costs for banks became markedly lower and more volatile on quarter-ends. Contrary to the case of unsecured rates, the quarter-end effects have weakened in the repo market, on net, reflecting lower dealer leverage and reduced net repo financing. Another notable change is the disappearance of the well-documented day-of-week effects on the federal funds rate, mainly due to the abundance of reserve balances.

Money markets went through important changes within the ELB sample as well. We document that the ON RRP facility has strengthened the link between the repo rates and unsecured rates, and also contributed to better transmission from the federal funds market to other unsecured funding markets. Moreover, volatility of all rates dampened with an especially notable decline in the repo market. We also find that the tendency of foreign banks to reduce their overnight borrowing on financial-reporting-related days, combined with the search by cash lenders for alternative investment opportunities, exacerbated month-end and quarter-end effects on the federal funds rate and Eurodollar rates later in the ELB sample, the period associated with the new regulations. The availability of the ON RRP as a viable investment option on financial reporting days, when alternatives are limited, reduced the potential for sharp drops in the repo rate, as empirically verified in our analysis.

To the best of our knowledge, this is the first study to document how money markets, which are at the core of monetary policy transmission, have been affected by the changing monetary policy framework and the new regulations. In related literature on money market dynamics, Afonso et al. (2011) analyze activity in the federal funds market during the global financial crisis, while Copeland et al. (2014b) and Gorton and Metrick (2012) focus on the repo market in the context of runs. Yoldas and Senyuz (2015) model the behavior of term money market rates and quantify stress thresholds. Although the literature on monetary policy transmission to the economy is vast, there is relatively limited research on how the target rate is transmitted to other overnight interest rates. Bech et al. (2014) find evidence of deterioration of the pass-through from the federal funds rate to the repo rate during the financial crisis that seemed to persist, while Kroeger and Sarkar (2016) suggest that this pass-through improved with the ON RRP facility.

Another strand of literature that is related to our work documents the effects of certain calendar days on money market rates. Spindt and Hoffmeister (1988), Griffiths and Winters (1995), Hamilton (1996), Carpenter and Demiralp (2006), and Judson and Klee (2010) show that the federal funds rate exhibits calendar-day effects associated with the maintenance period as well as quarter-ends. More recently, Munyan (2015), and Anbil and Senyuz (2016) document the effects of window dressing activity on financial reporting dates in the repo market.

The rest of the paper is organized as follows. In the next section, we provide background information on the mechanics of money markets, review changes in the monetary policy implementation framework and relevant regulations, and establish hypotheses on their effects. We describe the data set in Section 3 and lay out the methodological framework in Section 4. We present and discuss the estimation results in Section 5. Section 6 concludes.

2 Money Markets and the Changing Landscape

2.1 Bank Reserves and Activity in the Federal Funds Market

Banks are required to maintain a minimum level of reserves at the Federal Reserve Banks in their Districts.[1] Historically, banks avoided holding excess reserves, as such balances did not earn any interest. Indeed, total reserve balances in the banking system averaged about $10 billion in 2007, while total bank assets were close to $10 trillion over the same period. As can be seen in Figure 1, reserves in the system increased to more than $800 billion at the end of 2008 as the Fed provided ample liquidity during the financial crisis through several facilities.[2] Following subsequent rounds of asset purchases from 2009 to 2014, total reserve balances averaged nearly $2.5 trillion in 2016.[3]

[1]We will be referring to depository institutions with reserve accounts simply as banks. See Regulation D Reserve Requirements for a full list of financial institutions in this category, available at `https://www.federalreserve.gov/boarddocs/supmanual/cch/int_depos.pdf`.

[2]See `https://www.federalreserve.gov/monetarypolicy/bst_crisisresponse.htm` for details on the Fed's crisis response, and `https://www.federalreserve.gov/monetarypolicy/expiredtools.htm` for a list of expired liquidity provision facilities.

[3]Between November 2008 and October 2014, the Fed purchased nearly $1.7 trillion in Treasury securities and about $2 trillion in agency mortgage-backed securities, as well as $170 billion in agency debt securities in order to put downward pressure on longer-term interest rates. See d'Amico et al. (2012) and Krishnamurthy and Vissing-Jorgensen (2011) for a discussion of the economic rationale and effects of large scale asset purchases.

The unprecedented increase in the reserve balances changed the landscape for the federal funds market. Federal funds are unsecured loans of reserve balances between banks and other eligible institutions, mainly GSEs. Federal funds transactions are typically conducted for an overnight term and are carried out either directly between the institutions or through third-party brokers. Historically, transactions in the federal funds market facilitated the redistribution of reserve balances, whereby banks with reserve balances in excess of the required levels lent to banks in need of reserves. The surge in reserve balances led to a substantial decline in banks' need for short-term borrowing to cover idiosyncratic funding shortfalls. To ensure monetary control and promote efficiency in the banking system, the Fed introduced the IOR as a new monetary policy tool in October 2008. As a result, incentives for banks to lend federal funds at rates below the IOR were largely eliminated.

As shown in Figure 1, the outstanding amount of federal funds borrowed by banks declined to roughly one fourth of the level observed prior to the global financial crisis by 2011, and it has remained low since then. Moreover, volume in the federal funds market declined from $200 billion per day in 2007 to $60 billion per day at the end of 2012 according to Afonso et al. (2013b), who also estimate that banks that provided more than half of the federal funds sold before the crisis accounted for only a fraction of the lending activity after 2008. GSEs that are not eligible to earn IOR have been the main lenders in the post-crisis period.[4] On the borrowing side, Afonso et al. (2013a) show that mostly banks under the umbrella of bank holding companies and foreign banking organizations have been purchasing federal funds from GSEs for arbitrage purposes.[5] These institutions borrow federal funds at rates below the IOR and place the cash in their reserve accounts to earn the spread between the IOR and the federal funds rate. These transactions have been relatively more profitable for foreign banks as they are not subject to assessment by the FDIC.[6]

The changing landscape in the federal funds market raises the important question of whether the pass-through from the federal funds rate to other overnight rates has been affected over

[4] Specifically, it is the Federal Home Loan Bank System that dominated the supply side of the federal funds market. See Ashcraft et al. (2010) for a detailed description of this system and its role as a liquidity provider to banks.

[5] In the current context, foreign banking organizations are U.S. branches and agencies of foreign banks.

[6] In 2011, the FDIC changed the assessment base for its deposit insurance scheme from domestic deposits to total assets minus equity, making larger balances more costly for domestic banks regardless of funding source. See Kreicher et al. (2013) for a detailed discussion.

time. In addition, superabundant reserves may have implications for cash flows in the market associated with days of reserve maintenance period.[7] In the pre-crisis era, activity in the federal funds market was in part driven by maintenance period dynamics, as shown by Spindt and Hoffmeister (1988), Griffiths and Winters (1995), and Hamilton (1996) among others. However, superabundant reserves, combined with the finding by Ennis and Wolman (2015) that reserves in the system have been fairly widely distributed across banks since mid-2009 suggest that calendar effects associated with reserve maintenance have likely dissipated in the post-crisis era.

2.2 Other Money Market Segments

The monetary policy implementation by the Fed relies on targeting the federal funds rate and cross-market linkages across money markets. Particularly, overlapping participants in various money market segments and arbitrage activity ensure strong co-movement that the Fed relies on for effective transmission of its monetary policy.

The Eurodollar market is another segment for unsecured funding that is broader than the federal funds market. Eurodollars are U.S. dollar-denominated deposits held in a bank or a bank branch located outside of the United States. U.S. banks and foreign banking organizations cannot directly borrow in the Eurodollar market but can take Eurodollar deposits, mainly through their Caribbean branches, and transfer them *onshore* to fund U.S. operations. Eurodollar deposits that remain outside the United States are not covered by FDIC deposit insurance, while those that are transferred to an insured U.S. affiliate are included in the deposit insurance assessment base. Because of their unsecured nature and regulatory treatment, Eurodollar deposits constitute a close substitute to federal funds. However, the Eurodollar market has a more diverse set of participants compared with the fed funds market, as participants do not have to have an account at the Fed. Cipriani and Gouny (2015) estimate that the average volume in the brokered Eurodollar market is three to four times larger than the brokered federal funds market.[8]

The major segment of the money market for secured funding is the market for repurchase agreement (repo). A repo is effectively a collateralized loan in which the lender of the cash

[7]See the Reserve Maintenance Manual for reporting requirements as well as calculation and maintenance of reserve balances, available at `http://www.federalreserve.gov/monetarypolicy/files/reserve-maintenance-manual.pdf`.

[8]There has been a drop in the Eurodollar volume following the money fund reform compliance date in October 2016 as prime funds pulled back from lending in this market.

receives the security as a collateral and the borrower pays the lender interest on the loan. Sale of securities takes place under an agreement to repurchase them at a specified price on a later date.[9] The repo market can broadly be divided into two parts: the bilateral market where the two parties interact directly, and the triparty market where clearing/brokerage services of a third-party is involved. Total volume of the Treasury repo market is well above $2 trillion.[10] Cash borrowers (or securities lenders) in the repo market include banks and securities dealers while money market mutual funds (or money funds) and government-sponsored enterprises (GSEs) are among the biggest lenders of cash (or borrowers of securities).

The final segment of the money market we consider is the commercial paper market, in which large corporations issue debt for a fixed maturity. Many companies issue commercial paper when they need to raise short-term cash as it is a lower cost alternative to bank loans. Although commercial paper is unsecured, it is considered a very safe investment as typically only creditworthy companies with high credit ratings issue such securities. Commercial paper is especially attractive for institutional investors like money funds as they are liquid and have a low risk of default.

2.3 Monetary Policy Implementation Framework

Historically, adjustment of the level of reserve balances in the banking system to move the effective federal funds rate toward the target level set by the FOMC was the central pillar of monetary policy implementation. Given scarce reserve balances in the system, the Fed would affect the market rate by announcing a target level and managing the amount of reserves available to the banking system through open market operations (OMOs). These operations would influence the rate in the federal funds market, where banks experiencing shortfalls could borrow from banks with excess reserves. Given the small volume of reserves at the Fed, around $10 billion, even small OMOs could significantly affect the market rate. Changes in the federal funds rate would then be transmitted to other short-term interest rates, to longer-term interest rates, and eventually to

[9] Fed transactions in the repo market are defined from the point of view of the market participants, that is, a transaction in which securities are lent by the Fed in lieu of cash is called a reverse repo.

[10] See Copeland et al. (2014a), Baklanova et al. (2016) for specific estimates and breakdowns into different segments.

inflation and economic activity. This framework worked seamlessly while the Fed was operating with a balance sheet of less than $1 trillion before the crisis.

The global financial crisis forced changes in the operational framework of the Fed.[11] In an environment with superabundant reserves, the conventional approach based on changing the quantity of reserves via OMOs would not work. As a result, the Fed extended its monetary policy toolkit. In the fall of 2008, the Fed started paying interest on banks' reserve balances, which became the primary tool of its new monetary policy implementation framework in controlling short-term interest rates.

Although adjusting the IOR is an effective way to move market interest rates in an environment of superabundant reserves, federal funds have generally traded below this rate, mainly due to the fact that only banks can earn the IOR. GSEs, the other major group of participants in the federal funds market, still have an incentive to lend at rates below the IOR as they do not receive interest on their reserve accounts. Moreover, FDIC fees and other balance sheet constraints, such as capital and liquidity regulations, limit arbitrage activity by banks that would push the market rate toward the IOR.

In order to enhance monetary control and put an effective floor under short-term interest rates, the Fed introduced the ON RRP facility as a supplementary tool for its implementation of monetary policy. ON RRPs are offered to a broader set of financial institutions, including money funds that do not have access to the federal funds market. In September 2014, the FOMC issued a statement summarizing the new operating strategy, and in December 2015, it successfully lifted the federal funds rate from its near-zero range in this framework.[12]

The primary tool of the new operating framework, IOR, has important implications for the transmission of monetary policy from federal funds to the repo market. In the pre-crisis era, the active presence of large banks in both the federal funds and repo markets was crucial to the co-movement of these two rates. The unsecured nature of the federal funds transactions has typically resulted in a small and positive spread between the federal funds rate and the rate on repo transactions where the underlying collateral is a U.S. Treasury or agency security.

[11] See Ihrig et al. (2015) for an in depth discussion of the evolution of the Fed's monetary policy implementation framework through the financial crisis and its aftermath.

[12] See https://www.federalreserve.gov/monetarypolicy/policy-normalization.htm for further details on policy normalization. Anderson et al. (2016) provide an overview of money market developments after the liftoff.

However, market-determined, or effective, federal funds rate printing below the repo rates became a frequent phenomenon amid superabundant reserves and the ELB on the funds rate. The negative spread reflects reduced scope for arbitrage activity due to IOR, aside from the dramatic reduction in banks' needs for short-term borrowing, as discussed previously. Specifically, when the repo rates were greater than the federal funds rate in the past, banks could borrow in the federal funds market and place the cash in the repo market, creating downward pressure on the repo rates and pushing the effective federal funds rate up. However, in the presence of the IOR, the incentive for banks to engage in arbitrage activity across the federal funds and repo markets exists only when the repo rates are above the IOR. Although GSEs may also engage in this type of arbitrage, frictions—such as internal restrictions or intra-day timing considerations—likely limit such activity. As a result, we expect a weaker link between the effective federal funds rate and the repo rates in the ELB sample, on net.

The supplementary monetary policy tool of the new framework, the ON RRP facility, has also been affecting overnight funding dynamics since its inception in September 2013. The Fed has been offering ON RRPs on a daily basis at a pre-announced offering rate. Through this facility, the Fed borrows cash from eligible counterparties in exchange for Treasury securities from its open market portfolio. These operations provide an investment vehicle for money market participants who usually compare the facility's offering rate with rates in the market and determine whether to bid in the ON RRP operation.

The ON RRP operations, are in essence, similar to the temporary OMOs in the form of reverse repos conducted by the Fed prior to the crisis, but there are also important differences. Participation in the ON RRP operations are open to a wide range of entities, including money funds, banks, and GSEs, in addition to the primary securities dealers. Indeed, Frost et al. (2015) show that money funds have been the dominant cash lenders in ON RRP operations. Therefore, by expanding the set of alternative investments available to money funds and GSEs, the ON RRP is expected to contribute to improved alignment of secured and unsecured funding rates. The second important difference of the ON RRP from conventional temporary OMOs is that the latter was conducted to move the effective federal funds rate close to the FOMC's target, while the former is intended to set a floor for the overnight rates. The mechanism is similar to that of IOR for banks in the federal funds market; ON RRP counterparties do not have an incentive to invest in alternative sources unless they are offered the ON RRP rate or higher. Indeed, Potter (2015) shows that the ON RRP has established a *soft* floor, as the FOMC intended—that is, although some trades likely occur below the ON RRP rate, volume-weighted average overnight funding rates have mostly been above the offering rate. A general reduction in the volatility of overnight rates is another expected effect of the soft floor set by the ON RRP. Such effects are likely to be especially important on financial-reporting days when borrowers contract the size of their balance sheets, leaving cash lenders looking for alternative safe investment options.

Take-up at the ON RRP facility trended up for about a year following its inception in September 2013, as can be seen from Figure 2. One year later, the FOMC reduced the overall limit on the facility substantially (from $1.4 trillion to $300 billion) and introduced an auction process to allocate reverse repos in the event that the overall limit is binding. This change led to a sharp drop in money market rates on that quarter-end as it left cash lenders scrambling for alternative investments. In October 2014, the FOMC authorized a series of term RRPs spanning year-end to help address downward pressure on rates. In contrast to the third quarter, money market rates generally stayed at or above the ON RRP rate at year-end, suggesting that perceived investment capacity is an important factor in determining the effectiveness of RRPs in supporting rates.

At the time of the rate hike in December 2015, the aggregate cap on ON RRP operations was temporarily suspended. Currently, the ON RRP operations are limited only by the value of the Treasury securities in the Fed's open market portfolio that are available for these operations, which stand around $2 trillion.

2.4 New Banking Regulations and Dealer Leverage

The announcement and implementation of Basel III capital and liquidity reforms had a significant effect on the post-crisis financial landscape. In terms of their effects on money markets, the liquidity coverage ratio (LCR) and the leverage ratio are of particular interest among the Basel III reforms.

The LCR rule requires banks to hold high-quality liquid assets (HQLA) to meet cash outflows under a 30-day stress scenario. Therefore, it has potential implications for bank activity in overnight money markets as many assets and liabilities closely tied to these markets are under the jurisdiction of the LCR. U.S. banking regulators proposed an LCR rule in October 2013 and finalized it about a year later. Although lending in the federal funds market reduces the LCR numerator because reserves are counted as HQLA, cash inflow assumptions applied to regulated financial institutions typically imply limited or no impact of such activity on the LCR, on net.[13] Similarly, treatment of collateral in case of repo transactions for LCR purposes implies that lending in the repo market (in which the underlying collateral is in the HQLA category) has no effect on a bank's LCR. On the borrowing side, funding non-HQLA assets through either unsecured interbank borrowing or repos causes a deterioration in the LCR, creating an incentive for banks to reduce their reliance on such financing. However, by the time the initial LCR announcement was made, banks had already reduced their reliance on wholesale funding substantially—see for example Choi and Choi (2016). Meanwhile, IOR arbitrage trades actually increase a bank's LCR, as the borrowed cash is parked in the arbitrageur bank's reserve account, which is treated as HQLA with no haircuts, and the cash outflow assumption associated with the borrowing results in a less-than-proportional increase in the denominator. All told, we do not expect the marginal effect of the LCR to be material for overnight money market dynamics.

Another notable aspect of Basel III for money market activity has been the introduction of the leverage ratio requirement. This framework requires banks to hold Tier 1 equity equivalent to at least 3 percent of their leverage exposure calculated using their on- and off-balance-sheet assets, including reserves. The Supplementary Leverage Ratio, the regulation that implements the Basel III leverage ratio provisions in the United States, bases the relevant calculations on averages of *daily* values for on-balance-sheet items. In contrast, for most foreign banks, disclosures are based on month- or quarter-end levels. This regional difference in the implementation of Basel III incentivized foreign banks to contract their balance sheets on financial reporting days and expand on other days. Although the leverage ratio requirement will not become binding until 2018, it was announced in mid-2013, and banks started disclosing their leverage ratios to public in January 2015 including three quarters of historical data. Becoming compliant before the beginning of public disclosures was an important motivation for banks to make adjustments to their balance sheets. As a result, we expect stronger financial reporting day effects in the federal funds and Eurodollar markets in the ELB sample after the introduction of the leverage ratio requirements.

[13] In the LCR calculation, cash inflows and outflows over the 30-day stress period are aggregated and netted. Specific rates are applicable to different assets and liabilities, and in some cases lending in the federal funds market may decrease the LCR of the lending bank.

Declining leverage of securities broker dealers has been another important feature of the post crisis landscape (Adrian et al. (2013)). Dealers were not subject to leverage limits prior to the crisis as they were outside the regulated banking system. However, four out of the five major stand-alone investment banks with dealer arms have been integrated into bank holding companies either via acquisitions or conversions. This change has been among the main drivers of lower dealer leverage along with generally increased risk aversion in the aftermath of the crisis.

Dealers dynamically adjust their balance sheets mainly through short-term borrowing in the form of repos, as discussed in Adrian and Shin (2010). Along with overall leverage, repo activity of dealers also declined relative to the pre-crisis norms. As can be seen from Figure 3, although repo-based lending by dealers has been relatively stable since 2001, their borrowings through repos have been notably lower since 2007. The change in *net* repo financing is more dramatic: The ratio of net repo liabilities to total liabilities for dealers has been steadily decreasing since its peak in 2007 and reached about 8 percent in 2015, almost one fourth of its level in 2007. Against this backdrop, we expect weaker quarter-end effects on repo rates in the ELB sample, as the aforementioned developments likely reduced the scope for quarter-end window dressing compared with the pre-crisis era. Moreover, the ON RRP facility further limits the effects of financial-reporting days on repo rates by setting a floor. in Table 1, we summarize all the aforementioned changes in the monetary policy and the regulatory environment, as well as their anticipated effects on overnight money market dynamics.

3 Data

Our sample covers two main periods: the pre-crisis period that spans from January 2, 2001, to July 31, 2007; and the ELB period that runs from December 17, 2008, to August 28, 2015.[14] The former is associated with the conventional monetary policy operating framework and serves as a benchmark while the latter is a period during which overnight money markets were subject to all the significant changes discussed above.

Our data set consists of four overnight money market interest rates. The first one is the effective federal funds rate (EFFR), which is calculated as a volume-weighted average of rates on

[14] We exclude the period from mid-2007 to late 2008 from our analysis as this period is associated with unprecedented movements in the rates driven by the financial crisis.

brokered federal funds trades and published by the Federal Reserve Bank of New York (FRBNY). The second one is the Eurodollar rate (EDR) which represents the cost of alternative unsecured funding for large banks. We use the EDR data that the FRBNY started collecting in March 2010. Prior to this date, we use the data obtained from Wrightson ICAP in the ELB sample. For our pre-crisis analysis, we substitute the EDR with the overnight London Interbank Borrowing Rate (LIBOR), obtained from Bloomberg, because Eurodollar data are not available for that period. LIBOR is a commonly-used indicator for the average rate at which banks may get short-term loans in the London interbank market, and it serves as reference rate for various debt instruments.[15] The third key rate in our analysis is a representative rate of secured funding from the repo market. We use the volume-weighted average rate for Treasury GC repo obtained from the FRBNY, which we will refer to as RPR. Finally, we use the overnight AA nonfinancial commercial paper rate (CPR) released by the Federal Reserve Board.[16] An important feature of the CPR in our context is that it represents an unsecured funding rate that is not directly affected by the changing monetary policy framework and new banking regulations discussed above.

Visual investigation suggests very strong co-movement among the rates during normal times (Figure 4). Moreover, the sample means and standard deviations of the rates are remarkably close in the pre-crisis period, as shown in Panel A of Table 2. However, as one can infer from Figure 5 and Panel B of Table 2, the co-movement of rates appears to have weakened over the ELB period, on net. For example, RPR remained especially elevated relative to unsecured rates around late 2011, reportedly due to longer dealer positioning in Treasury securities that coincided with the Fed's Maturity Extension Program as well as higher Treasury debt issuance.[17] In addition to weaker co-movement, calendar effects relative to the level of the rates seem stronger, on average, over the ELB period and the sample moments also show more variation across the rates. In the next section, we lay out the empirical framework to quantify such differences and analyze them in detail.

[15] See Hou and Skeie (2014) for a detailed description of the rate-setting mechanism and efforts to reform the LIBOR.

[16] Data are available at `www.federalreserve.gov/releases/cp/`.

[17] During this program, the Fed sold about $650 billion of short-term securities and used the proceeds to buy longer-term securities. By extending the average maturity of its securities portfolio, the Fed aimed to put downward pressure on longer-term interest rates to ease conditions in financial markets.

Another difference between the two samples is related to the degree of stationarity of the rates. As shown in Table 3, in the pre-crisis sample, we cannot reject the null of a unit root in the interest rates at any conventional significance level with respect to both the augmented Dickey and Fuller (1979) (ADF) test statistic and the Elliott et al. (1996) (ERS) point-optimal test statistic. In contrast, we reject the null of unit root for all rates in the ELB sample according to the ADF test statistics, with the exception of CPR, and for all rates according to the ERS test statistic. Therefore, the interest rates are well approximated by integrated processes with a likely common stochastic trend in the pre-crisis sample, reflecting the fact that this period contains a full monetary policy cycle with easing early in the period followed by a gradual tightening beginning in 2004. In the ELB period, the rates are persistent but not integrated against the backdrop of no change in the FFR target. Our modeling strategy incorporates this important difference in rate dynamics.

4 Models

We specify models that account for co-movement and persistence of the rates as well as time-variation in their volatilities and cross-correlations. We also allow for various calendar factors that likely affect dynamics of rates on specific days. We estimate two different models for the pre-crisis and ELB periods as unit root tests suggest that the interest rates are well-approximated by integrated processes in the pre-crisis sample while they are persistent but stationary during the ELB sample.

The pre-crisis model is a vector error correction (VEC) process that incorporates the long-run equilibrium relationship of overnight money market rates. Let y_t denote the vector of the interest rates at time t, that is, $y_t = (EFFR_t, RPR_t, LIBOR_t, CPR_t)'$ in the pre-crisis sample. The interest rate dynamics are characterized by the following VEC model:

$$\Delta y_t = Ad_t + \beta \Delta TFFR_t + \sum_{j=1}^{p} \Phi_j \Delta y_{t-j} + \Theta z_{t-1} + \epsilon_t, \tag{1}$$

where d_t is a vector of indicator variables for calendar effects, which we will explain in detail; $TFFR$ is the target federal funds rate; z_t is a vector of error correction terms; and ϵ_t is a zero-mean martingale difference vector process, which is possibly heteroskedastic. Reflecting the pre-crisis monetary policy operating framework, we impose the restriction that there are three distinct co-integrating relationships and that all of them involve EFFR. Formally, we have $z_{it} = y_{1t} - (c_i + \gamma_i y_{i+1,t})$ where $i = 1, 2, 3$.[18]

The vector of calendar effects, d_t, contains 10 indicator variables to account for reserve maintenance period days, 2 indicators for elevated payment days within a month (15th and 25th), 2 for financial reporting days (month-end and quarter-end), and a dummy variable to control for the brief disturbance in money markets caused by the September 2001 terror attacks. As a result, the model does not contain a constant vector because it cannot be separately identified given the set of maintenance period indicators. We set $p = 4$ based on Schwarz information criterion.[19]

There exists a mapping from this VEC system to a VAR that can be defined for the level of interest rates. This mapping allows us to directly compare the results from the pre-crisis period with the ELB period as the model for the latter sample is a VAR in levels. Let Ψ_j for $j = 1, \ldots, p+1$ denote the autoregressive coefficient matrices in the implied VAR. Then we have $\Psi_1 = \Phi_1 + I + \Theta\Gamma$ where I is an identity matrix, $\Gamma = (i, -diag\{-\gamma\})$, i is a vector of ones, γ is the vector of co-integration slopes given previously, and $diag(.)$ indicates a diagonal matrix, $\Psi_j = \Phi_j - \Phi_{j-1}$ for $j = 2, \ldots, p$, and $\Psi_{p+1} = -\Phi_p$.[20]

For the ELB period, we specify the following VAR model in levels given the stationary behavior of interest rates in this sample:

$$y_t = \Pi d_t + \sum_{j=1}^{p} \Xi_j y_{t-j} + \epsilon_t, \tag{2}$$

where d_t is now a 9×1 vector that contains month-end, quarter-end, day-of-week, and elevated payment flow-day indicators.[21] Note that the EDR replaces the LIBOR in this sample, so that $y_t = (EFFR_t, RPR_t, EDR_t, CPR_t)'$. We set $p = 3$ based on Schwarz model selection criteria.[22]

[18]We obtain very similar results when we estimate the number of co-integrating relationships as well as the co-integration parameters in a less restricted fashion as in Johansen (1995).

[19]Total number of parameters to be estimated is equal to 140, which results in approximately 46 observations per parameter.

[20]A caveat is that in the pre-crisis model, shocks are permanent due to the modeling of interest rates as integrated processes.

[21]Day-of-week indicators replace those for maintenance period days as the latter become insignificant amid abundant reserves in the ELB period.

[22]This model has 84 parameters to be estimated, resulting in 78 observations per parameter.

Both visual investigation and formal testing of the model residuals suggest significant volatility clustering in both sample periods. Hence, we estimate multivariate GARCH models for the second moments. Our modeling strategy closely follows that of Bollerslev (1990); however, instead of assuming a constant conditional correlation matrix, we allow for different correlation structures on financial reporting days. Therefore, our specification can be thought of as a hybrid of the constant correlation model and the dynamic correlation model of Engle (2002), who postulates a fully time-varying conditional correlation matrix. Let $E(\epsilon_t \epsilon_t' | \Omega_{t-1}) = H_t$ where Ω_t is the information set at time t, then we can write:

$$H_t = D_t R_t D_t, \tag{3}$$

where $D_t = diag\left\{\sqrt{h_{it}}\right\}$, $h_{it} = Var(\epsilon_{it}|\Omega_{t-1})$ and $R_t = Corr(\epsilon_t|\Omega_{t-1})$. The individual variances are modeled via the following GARCH specification:

$$h_{it} = \omega_i + \tau_i \epsilon_{i,t-1}^2 + \delta_i h_{i,t-1} + \lambda_{i,1} I_{m,t} + \lambda_{i,2} I_{q,t},\ i = 1, \ldots, 4, \tag{4}$$

where I_m and I_q are month-end and quarter-end indicators, respectively. In this specification, the variance at time t is essentially a weighted average of its lagged value, the new information at time $t-1$ that is captured by the most recent squared residual, the long-run unconditional variance, and the level shifts in volatility on financial reporting dates. We estimate the GARCH equation under variance targeting so that ω_i is a function of the sample variance of $\epsilon_{i,t}$ and the mean vector of the indicator series. Finally, the correlation matrix R_t is specified as follows:

$$R_t = I_{m,t} R_m + I_{q,t} R_q + (1 - I_{m,t} - I_{q,t}) R_n, \tag{5}$$

where R_m, R_q, and R_n are correlation matrices of GARCH residuals, that is, $h_{it}^{-1/2}\epsilon_t$, at month-ends, quarter-ends, and all other days, respectively.

5 Empirical Results

5.1 Co-movement of Rates and Monetary Policy Transmission

Our estimates for the pre-crisis sample are consistent with the conventional monetary policy implementation framework. As shown in Panel A of Table 4 lagged EFFR terms are significant in all other rate equations, implying that interest rates were adjusting in response to changes in the policy rate. Moreover, the EFFR was not responding to changes in the other rates as indicated by the insignificance of lagged interest rates in the first column. The magnitude of response to changes in EFFR is estimated to be somewhat smaller for the LIBOR, likely reflecting a combination of non-synchronous trading as well as factors that may only affect offshore U.S. dollar funding markets. Other than the EFFR, no other interest rate in the system had predictive power for the remaining interest rates. In addition, as can be seen in Panel B, changes in the target federal funds rate are highly significant in all equations of the VEC model. Overall, these results show that funding rates were adjusting in response to policy intervention and dynamics in the federal funds market, consistent with the view that the overnight money markets were tightly connected through the federal funds market in the pre-crisis period.

The estimates from the ELB sample shown in Panel A of Table 5 paint a different picture. The federal funds and Eurodollar markets appear to be closely connected as indicated by the statistical and economic significance of the EFFR coefficients in the EDR equation. Similarly, the EFFR is linked to the CPR, which is another key unsecured rate in the system, although to a lesser extent than the EDR. Therefore, the EFFR continued to be an anchor for unsecured rates in the ELB period, although its transmission has been weaker relative to pre-crisis norms, especially in case of the CPR.

The most dramatic change across the two periods concerns the transmission from the federal funds to the repo market. The EFFR is neither an economically nor statistically important predictor of the RPR movements in the ELB period. Another difference is that dynamics in the repo and commercial paper markets appear to affect those in the federal funds market, although such effects are not economically large. Therefore, we conclude that co-movement of the EFFR with other rates became noticeably weaker in the ELB sample amid superabundant reserves, subdued trading, and dominance of IOR arbitrage trades in the federal funds market. Moreover, the disconnect between the EFFR and the RPR emphasizes the diminished role of banks as arbitrageurs, as discussed in Section 2.1.

To assess the effects of the ON RRP on money market dynamics, we now focus on the ELB period and estimate VAR models for the two subsamples separated by the inception of the ON RRP facility on September 23, 2013. Although the facility has initially been limited in terms of the overall size and the number of participants, this date provides a natural structural break point in the ELB sample. Moreover, our objective is to obtain estimates for the *average* effects of the ON RRP over a sufficiently long time period, so this split provides a good empirical setup to achieve that goal.

The comparison of the results summarized in Tables 6 and 7 suggests that the ON RRP have had two important effects. First, transmission from the EFFR to the other unsecured rates clearly improved: The sum of lagged EFFR terms increased from 0.23 to 0.29 in the case of the EDR and from 0.16 and 0.33 in the case of the CPR. Second, the RPR became a significant predictor of the EFFR movements, in contrast to the pre-crisis relationship where RPR was moving in response to changes in the EFFR, mainly as a result of cross-market arbitrage. Interestingly, the RPR has also become highly significant in the EDR and CPR equations, emphasizing the growing importance of the repo market. Hence, it appears that the ON RRP markedly improved the overall co-movement of overnight interest rates and transmission from the federal funds market to other segments of unsecured funding markets.

5.2 Reserve Maintenance Period Effects

In Figure 6, we report point and interval estimates for the coefficients of the effects of reserve maintenance days on the EFFR in the pre-crisis period. Clearly, maintenance period days have had small but economically meaningful and statistically significant effects on the EFFR. Due to elevated payment flows following weekends, the EFFR used to be firmer by 1 to 2 basis points on Mondays. By contrast, funds used to trade softer by a slightly greater magnitude on Fridays, as banks generally tried to avoid an excess position over the weekend during which reserves count for three days toward the reserve requirement. Tuesdays were also associated with softness due to reduced demand towards the middle of the week when payment flows are relatively lighter.

These estimates are consistent with those of Hamilton (1996), Carpenter and Demiralp (2006), and Judson and Klee (2010)) that were obtained in different empirical frameworks.

In the ELB period, although we cannot statistically reject day of the week effects in the federal funds market, our estimates (not reported) indicate economically miniscule effects. When we combine our coefficient estimates with trading volumes reported by Afonso et al. (2013b), we find that the average day-of-week effect is about only 3 percent of its pre-crisis level in dollar terms. Moreover, when we normalize the estimated effects by the standard deviation of the EFFR residuals to control for the dramatically different level of the average EFFR across the two periods, we find that the day-of-week effect is about 70 percent weaker in the ELB period. Therefore, we conclude that given the abundance of reserves and their fairly widespread distribution as reported by Ennis and Wolman (2015), reserve-maintenance effects in the federal funds market diminished substantially.

5.3 Market Dynamics on Financial Reporting Days

The estimated magnitudes of calendar effects are quite different across the pre-crisis and ELB periods as evident from Panel B in Tables 4 and 5. However, the average levels of overnight interest rates are dramatically different across the two samples. To control for the general level of interest rates and allow for a direct comparison between the two periods, we normalize the estimates relative to standard deviations of model residuals associated with the respective equation in the VAR system.

Figure 7 shows the *normalized* estimates for the two main samples. In the pre-crisis sample, all rates were subject to modest upward pressure at month-ends, possibly due to heavier payment flows as well as adjustments related to financial reporting. Most comprehensive financial reports are produced on a quarterly basis, so deleveraging by financial intermediaries on quarter-end is common practice. Indeed, quarter-end effects were more prominent than month-end effects, with the exception of the EFFR. Rates were markedly softer in the repo market, likely because securities-financing demand by dealers grew weaker on quarter-ends as these institutions actively managed their leverage. In contrast, it appears that reduced willingness to lend in unsecured markets on quarter-ends was the dominant factor leading to higher rates on financial reporting days. This pattern is observed especially for LIBOR, likely reflecting banks' desire to show strong liquidity positions on their financial statements and regulatory filings.

Money market dynamics on financial-reporting days changed materially in the ELB sample. First of all, both the EFFR and the EDR started softening on quarter-ends, mainly due to reduced borrowing driven by IOR-arbitrage trades by foreign banks and large domestic banks. Balance sheet constraints associated with the new FDIC assessment scheme and Basel III leverage ratio that became prevalent in the later part of the ELB sample largely explain reduced demand on the quarter-ends. Contrary to the case of unsecured rates, the quarter-end effect has become insignificant in the repo market, on net, likely reflecting a combination of factors. First, earlier in the ELB period, collateral demand was relatively strong due to flight-to-quality flows, leading to increased willingness to lend cash at lower rates in lieu of Treasury collateral. Second, later in the period, as new regulations were announced and implemented, lower dealer leverage and reduced net repo financing reduced the scope of quarter-end deleveraging effects. Finally, the availability of the ON RRP as a viable investment, especially on financial reporting dates when other investment options may be limited, reduced the potential for sharp falls in the repo rates. In addition, cash lenders' search for alternative investments on quarter-ends amid weaker demand by bank borrowers appears to have led to a softening in the CPR.

Figure 8 shows the normalized calendar effects on rates through the ELB period. Foreign banks report their leverage ratios based on only month-end or quarter-end observations as opposed to U.S. banks that are required to calculate their balance sheet ratios based on daily averages over a quarter. Consistent with this regional difference in the implementation of the leverage ratio, both the EFFR and the EDR started to decline notably at month-ends later in the ELB sample as foreign banks withdrew from the market. Moreover, downward pressure on these rates at quarter-ends also became more pronounced, especially for the EDR. This likely reflects the fact that Eurodollars are a relatively more important source of dollar funding for foreign banks, which are subject to less stringent implementation of the Basel III leverage ratio. In contrast, quarter-end effects on CPR have been relatively stable at the ELB, suggesting limited spillover effects from the federal funds and Eurodollar markets. The absence of direct implications on the nonfinancial commercial paper market also suggests that the leverage ratio requirements have indeed been the primary driver of dynamics of other unsecured rates on financial reporting days.

5.4 Volatility and Correlation of Overnight Interest Rates

We now focus on both general and financial-reporting-driven volatility dynamics across the two main sample periods as well as before and after the inception of the ON RRP facility. The parameter estimates of the volatility models for the pre-crisis and ELB samples are shown in Table 8. As expected, volatility of all rates declined substantially at the ELB in absolute terms. For example, the volatility of innovations in the EFFR equation declined from 5.6 basis points to only about 1 basis point. Meanwhile, the volatility process for the EFFR has become notably less persistent as captured by the decline in the sum of GARCH parameters ($\tau + \delta$) and more responsive to shocks as measured by the increase in the coefficient of the squared innovation (τ). Therefore, aside from calendar effects, which will be discussed in more detail below, volatility clustering has become more prevalent in the EFFR amid subdued trading activity in the federal funds market. In the case of the RPR, the volatility has become somewhat more persistent with a slight increase in sensitivity to shocks.

Figure 9 shows the estimated month-end and quarter-end effects on volatilities in the main sample periods.[23] As before, estimates are normalized by dividing by the standard deviations of residuals to allow for direct comparison across the two periods. Prior to the crisis, similar to the calendar effects in the conditional mean models, quarter-ends had larger effects on rate volatilities than month-ends. Especially, RPR exhibited substantial volatility clustering with around 2 to 5 times higher volatility on quarter-ends than other times. Quarter-end volatility in the RPR moderated notably at the ELB, but remained significant. This result, combined with insignificance of the quarter-end effect on the *level* of RPR, suggests that quarter-end dynamics in the repo market became more complex and led to movements in both directions in the post-crisis era. In contrast, the estimated quarter-end effect on the EFFR volatility increased substantially at the ELB.

Consistent with the soft floor set by the ON RRP, volatility of the overnight interest rates declined 35 to 50 percent in the second ELB subsample, as seen in Table 9. Moreover, the estimated parameters indicate a substantial reduction in the overall volatility clustering of the RPR, mainly led by a dramatic decline in the calendar effects (Table 9 and Figure 10). Indeed,

[23] Although based on asymptotic normal distributions, confidence bands are asymmetric, as we estimate them in the variance space and then convert to standard deviations.

the quarter-end spikes in volatility of the RPR due to collateral squeezes and reduced demand for funds by banks became statistically insignificant. Figure 11 illustrates the striking change in the RPR volatility. An important caveat is that the unconditional variances in our GARCH specifications are anchored to the corresponding sample variances, so the level shift after the ON RRP inception reflects the *average* effect across the two ELB samples. Elevated-volatility episodes in the fall of 2013 are related to the Treasury's debt limit and the government shutdown. Similar to the case of the RPR, the quarter-end effect on the CPR also became insignificant in the latter ELB sample. In contrast, month-end and quarter-end effects became more pronounced for the other unsecured rates, mainly due to the pullback from the unsecured markets by bank borrowers driven by the Basel III regulations.

Correlation structure of VAR innovations provides further insights into the co-movement of overnight interest rates. Table 10 reports estimates for the pre-crisis and ELB samples from the multivariate GARCH framework. Interestingly, the correlations of the EFFR residuals with those of the other three rates during normal times are fairly close across the two main samples. Hence, it appears that factors exogenous to the dynamic system of these rates, such as Treasury debt issuance and related liquidity effects, continued to operate in a similar fashion, on net. The EFFR innovations are most strongly correlated with those of the EDR in the ELB sample. Estimates reported in Table 11 suggest that this is largely due the aforementioned effects of the Basel III leverage ratio requirements that led to notably higher correlations on month-ends. Another notable change through the ELB period is the substantial decline in the EFFR-RPR correlation. The changing regulatory environment led to some movements in opposite directions in these two rates at month-ends and quarter-ends, while the ON RRP constrained downward movements in the RPR by setting an effective soft floor. For other rate pairs, it is not possible to make reliable comparisons, as most estimates are not statistically different from zero.

6 Conclusion

We analyze changing dynamics of overnight funding markets due to the global financial crisis and the associated policy response. To that end, we estimate systems of dynamic models for a set of key money market rates for both the pre-crisis era and the period from December 2008 to August

2015. In the latter period, the federal funds rate remained near zero and both monetary policy implementation and bank regulation changed notably. To the best of our knowledge, this is the first study to document the effects of these changes on money markets in a rigorous empirical framework.

Overall, co-movement of money market rates has weakened compared with the historical norms. Although the federal funds rate has mostly continued to provide an anchor for unsecured overnight interest rates, its transmission to the repo market has weakened. Moreover, the day-of-week effects on the federal funds rate have substantially diminished, likely reflecting the abundance of bank reserves and their fairly widespread distribution.

New banking regulations and the Fed's ON RRP facility introduced in 2013 have further transformed the money markets. For interest rates that represent unsecured wholesale funding costs for banks, movements around financial reporting days have been exacerbated due to increased balance sheet costs of large balance sheets in the new regulatory environment. Consistent with the intended effect of the ON RRP to set a soft floor for the rates, interest rate co-movement improved and volatilities, especially in the repo market, have substantially declined after the inception of the facility, on balance. Moreover, calendar effects in the repo market largely disappeared, reflecting diminished potential for drops in rates, as well as the availability of reverse repos with the Fed as a viable investment option around financial reporting days when other options may be limited.

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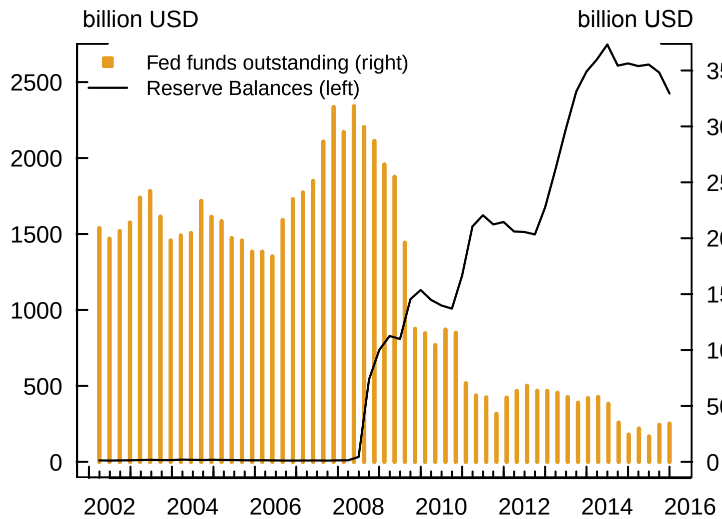
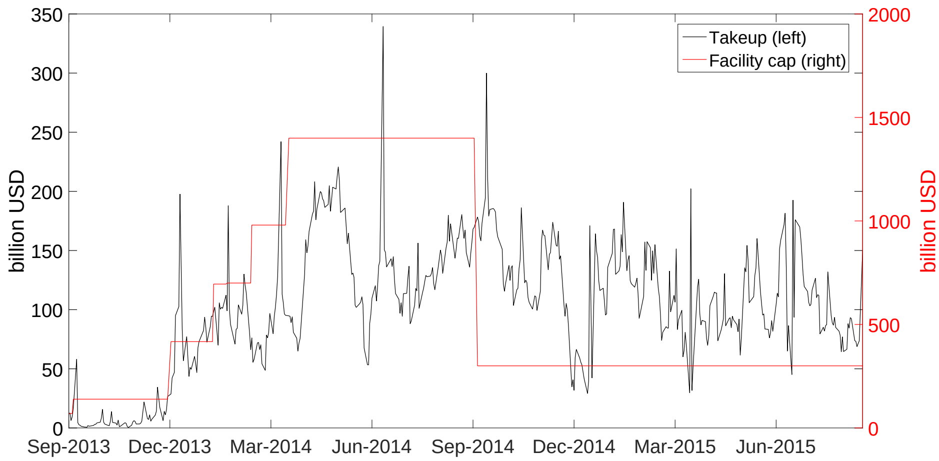
Figures and Tables

Figure 1: Reserves and Federal Funds



Note: Data are quarterly and obtained from Call reports.

Figure 2: ON RRP Operations

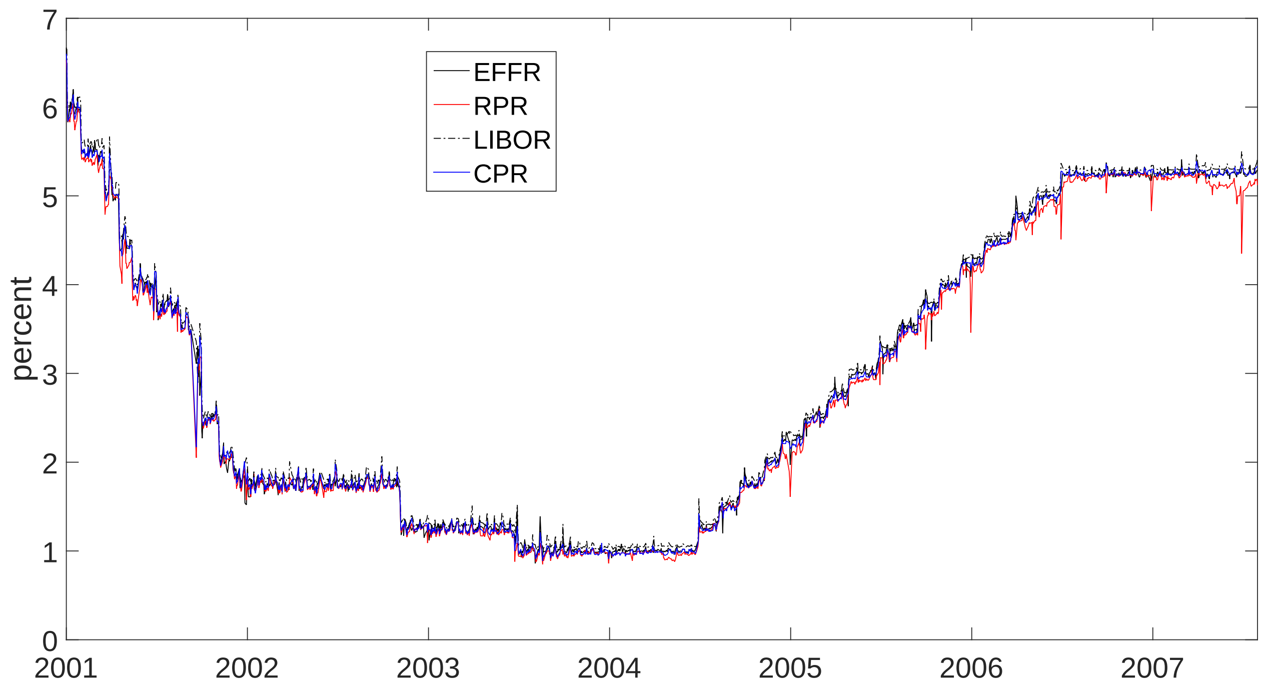


Note: Data are daily and obtained from FRBNY, available at `https://apps.newyorkfed.org/markets/autorates/temp`.

Figure 3: Repo Financing Activity by Securities Brokers and Dealers

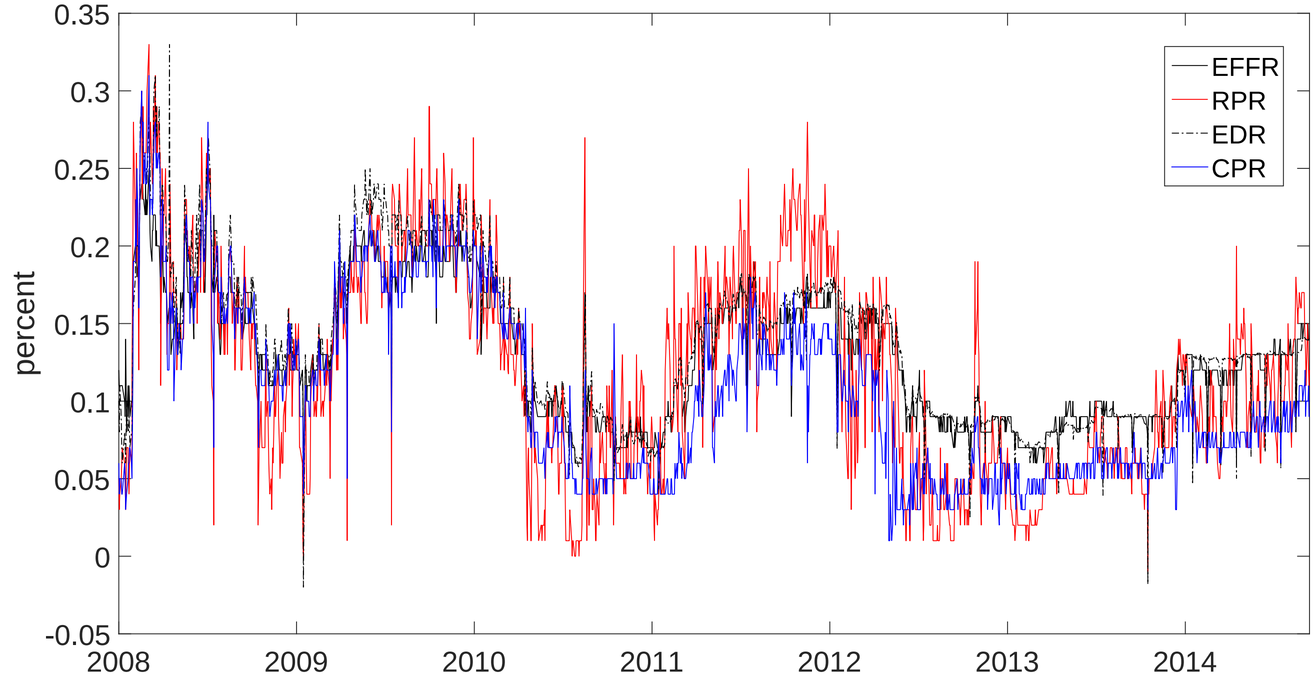
Note: Data are annual and obtained from the Financial Accounts of the U.S. statistical release (Z.1) of the Federal Reserve Board, available at `http://www.federalreserve.gov/releases/z1/`. TA (TL) denotes total assets (liabilities), RA (RL) denotes repo assets (liabilities), and NR is net repo financing, that is, RL–RA).

Figure 4: Overnight Money Market Interest Rates: 2001-2007



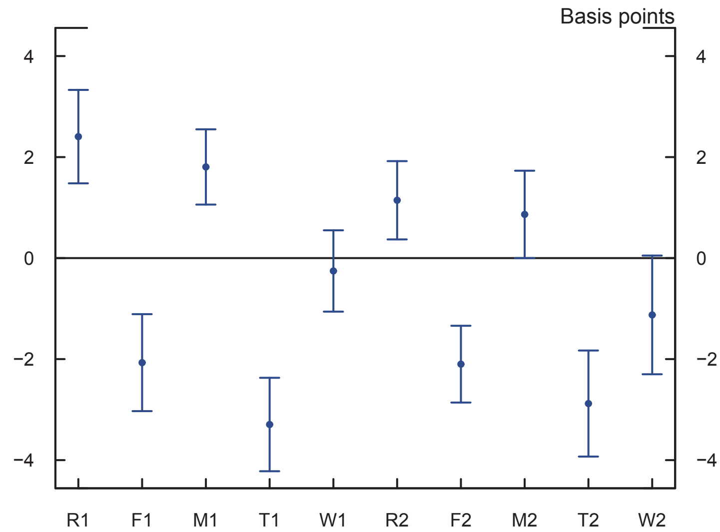
Note: Data are daily. EFFR and RPR are from FRBNY. Libor is from Bloomberg. CPR is from the commercial paper data release of the Federal Reserve Board.

Figure 5: Overnight Money Market Interest Rates: 2008-2015



Note: Data are daily. EFFR and RPR are from FRBNY. EDR is from FRBNY after March 2010, and from Wrightson ICAP prior to this date. CPR is from the commercial paper data release of the Federal Reserve Board.

Figure 6: Day of Maintenance Period Effects on EFFR during the Pre-Crisis Period



Note: Dots indicate point estimates and horizontal lines mark the boundaries of the 95 percent confidence bands. M, T, W, R, and F denote days of the week from Monday to Friday. The subscripts indicate whether the corresponding date is the first or the second one in the maintenance period.

Figure 7: Month- and Quarter-end Effects

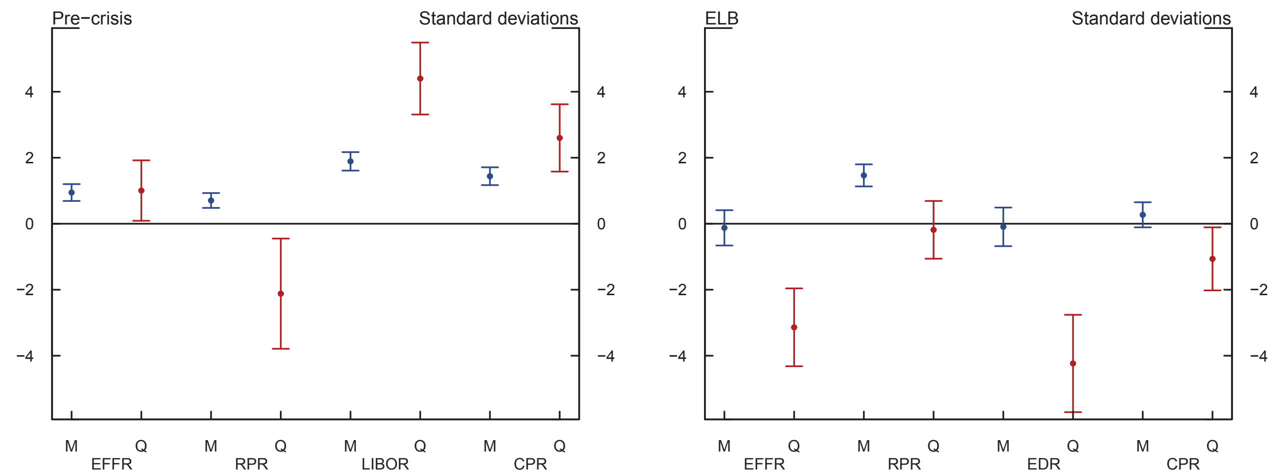
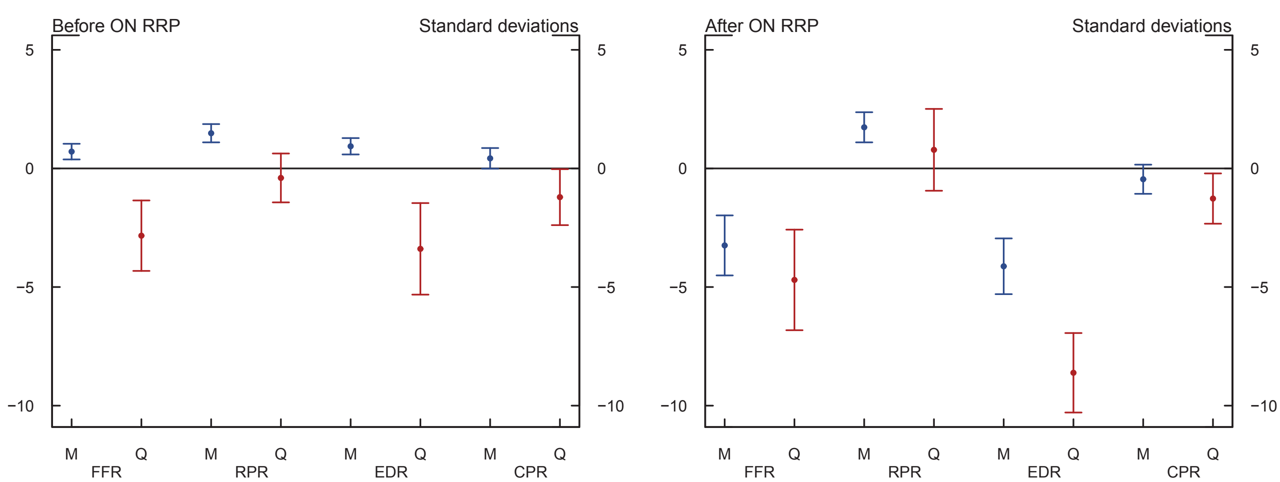


Figure 8: Month- and Quarter-end Effects within the ELB Period



Note: Dots indicate point estimates and horizontal lines mark the boundaries of the 95 percent confidence bands. M and Q denote month-end and quarter-end respectively. Effects are normalized with respect to the standard deviations of model residuals.

Figure 9: Month- and Quarter-end Effects on Volatility

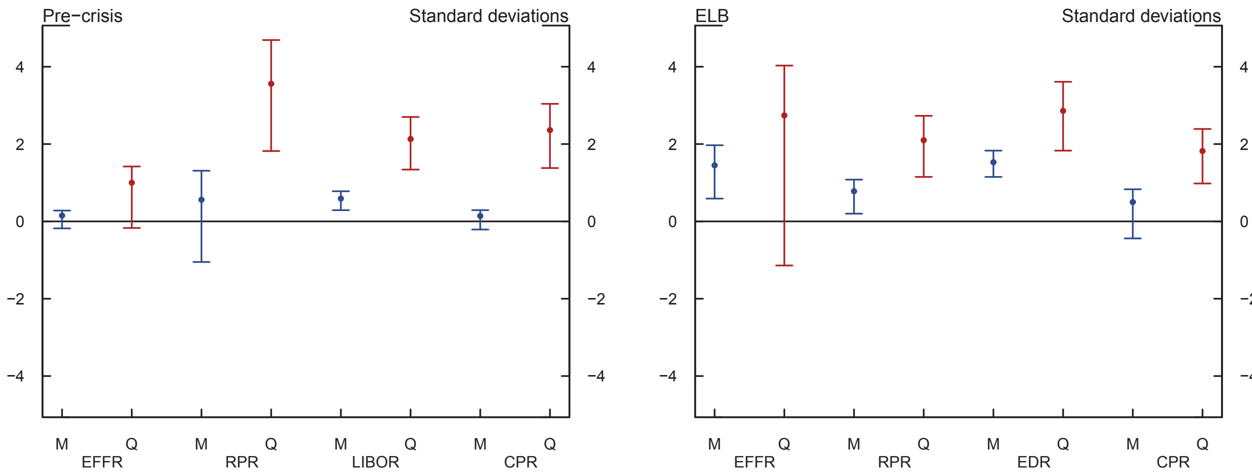
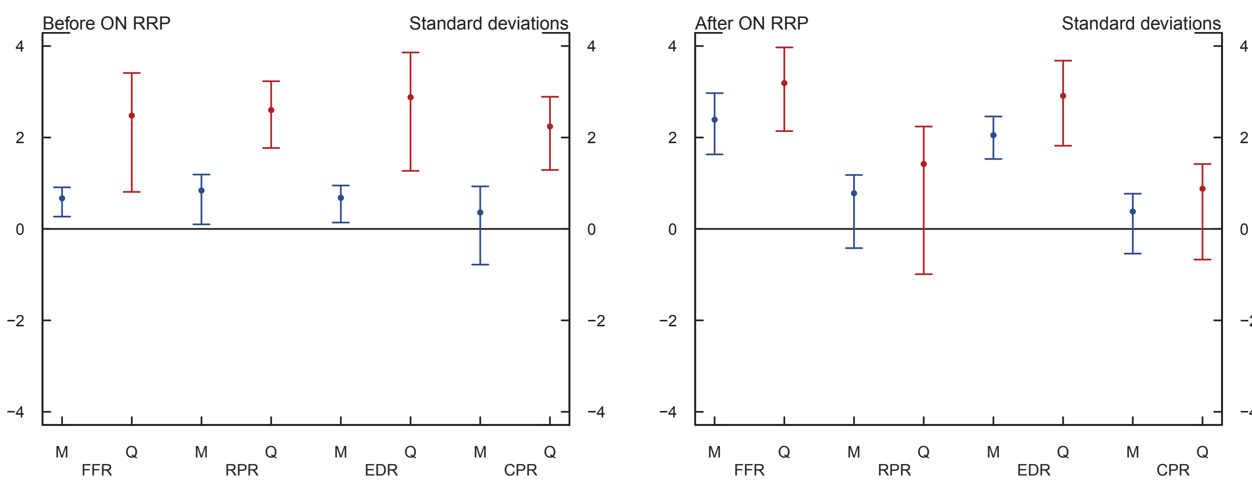


Figure 10: Month- and Quarter-end Effects on Volatility within the ELB Period



Note: Dots indicate point estimates and horizontal lines mark the boundaries of the 95 percent confidence bands. M and Q denote month-end and quarter-end respectively. Effects are normalized with respect to the standard deviations of model residuals.

Figure 11: Repo Rate Volatility and ON RRP

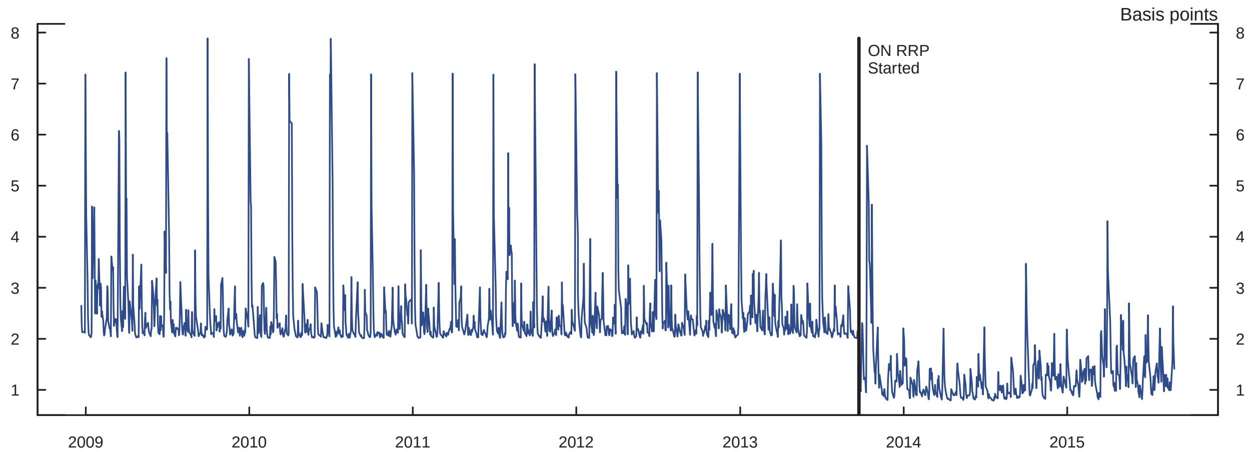


Table 1: Changes in Monetary and Regulatory Policy and Implications

Superabundant reserves and IOR	
Lower trading volumes in the federal funds market	(i) Weaker co-movement of EFFR with other rates (ii) Increased EFFR volatility
Reduced scope for EFFR-RPR arbitrage trades by banks	Weaker EFFR-RPR co-movement
Widespread distribution of reserves	MP effects diminish in the aggregate
ON RRP	
Inclusion of money funds and GSEs among counterparties	(i) Stronger co-movement of overnight interest rates (ii) Lower interest rate volatility (iii) Weaker financial reporting effects on RPR
New Regulations and Lower Dealer Leverage	
LCR	IOR arbitrage trades more attractive, but limited effect due to other regulatory constraints
FDIC assessment base change Leverage ratio	Stronger financial-reporting-day effects on unsecured rates and their volatility
Diminishing leverage and repo financing by dealers	Weaker financial-reporting-day effects on RPR

Table 2: Descriptive Statistics of Money Market Rates

	EFFR	RPR	LIBOR/EDR*	CPR
Panel A: Jan. 2, 2001-July 31, 2007				
Mean	2.937	2.881	2.999	2.927
Stdev	1.660	1.639	1.661	1.662
10th	1.010	0.980	1.058	0.990
50th	2.480	2.440	2.541	2.450
90th	5.250	5.220	5.301	5.250
AC(1)	0.999	0.999	0.999	0.999
Panel B: Dec. 17, 2008-Aug. 28, 2015				
Mean	0.129	0.118	0.137	0.107
Stdev	0.042	0.068	0.051	0.058
10th	0.080	0.030	0.080	0.040
50th	0.130	0.110	0.130	0.090
90th	0.190	0.210	0.210	0.190
AC(1)	0.954	0.920	0.950	0.958

Note: Data are daily. Mean, standard deviation and quantiles are reported in percent. AC(1) denotes first order autocorrelation.
* LIBOR is used for Panel A calculations and EDR is used in Panel B.

Table 3: Unit Root Tests

	EFFR	RPR	LIBOR/EDR*	CPR
Panel A: ADF Test				
Pre-crisis	-1.24	-1.31	-1.00	-1.02
ELB	-3.37	-3.17	-2.82	-2.52
Panel B: ERS Test				
Pre-crisis	251.3	275.6	158.2	195.7
ELB	1.2	2.8	2.5	3.4

Note: ADF is the augmented Dickey and Fuller (1979) test with the 1, 5, and 10 percent critical values of -3.44, -2.87, and -2.57, respectively. ERS is the point optimal test of Elliott et al. (1996) with the 1, 5, and 10 percent critical values of 1.99, 3.26, and 4.48, respectively.
* LIBOR is used for Panel A calculations and EDR is used in Panel B.

Table 4: Overnight Money Market Rates before the Financial Crisis

	EFFR	RPR	LIBOR	CP
Panel A: Autoregressive terms (sum)				
EFFR	0.947	0.449	0.345	0.521
	(0.00)	(0.00)	(0.00)	(0.00)
RPR	0.033	0.694	0.010	0.001
	(0.39)	(0.00)	(0.72)	(0.98)
LIBOR	0.016	-0.125	0.546	-0.091
	(0.91)	(0.41)	(0.00)	(0.43)
CPR	0.005	-0.021	0.099	0.570
	(0.97)	(0.92)	(0.21)	(0.00)
Panel B: Other variables				
ΔTFFR	0.454	0.406	0.337	0.416
	(0.00)	(0.00)	(0.00)	(0.00)
15th	5.50	6.04	6.10	7.00
	(0.00)	(0.00)	(0.00)	(0.00)
25th	4.33	0.69	0.09	1.14
	(0.00)	(0.24)	(0.75)	(0.00)
Month-end	5.33	4.15	7.43	6.20
	(0.00)	(0.00)	(0.00)	(0.00)
Quarter-end	5.66	-12.52	17.33	11.17
	(0.03)	(0.01)	(0.00)	(0.00)

Table 5: Overnight Money Market Rates at the ELB

	EFFR	RPR	EDR	CPR
Panel A: Autoregressive terms (sum)				
EFFR	0.911	0.107	0.223	0.153
	(0.00)	(0.21)	(0.00)	(0.02)
RPR	0.032	0.809	0.014	-0.011
	(0.00)	(0.00)	(0.29)	(0.47)
EDR	-0.024	0.048	0.705	0.000
	(0.53)	(0.50)	(0.00)	(1.00)
CPR	0.036	0.054	0.069	0.881
	(0.01)	(0.14)	(0.00)	(0.00)
Panel B: Other variables				
15th	0.80	3.29	0.85	0.96
	(0.00)	(0.00)	(0.00)	(0.00)
25th	-0.26	0.65	-0.08	0.37
	(0.01)	(0.08)	(0.36)	(0.05)
Month-end	-0.14	3.47	-0.13	0.37
	(0.63)	(0.00)	(0.72)	(0.20)
Quarter-end	-3.21	-0.41	-5.07	-1.58
	(0.00)	(0.70)	(0.00)	(0.03)

Note: Columns represent equations of the models. The sum of autoregressive terms correspond to $\sum \Psi_j$ in Table 4, and $\sum \Xi_j$ in Table 5, respectively, in terms of the notation of section 4. p-values based on robust (HAC) standard errors are reported in parentheses. Calendar effects are in *basis points*. Daily sample runs from January 2, 2001, to July 31, 2007, in Table 4, and from December 17, 2008, to August 28, 2015, in Table 5.

Table 6: Overnight Money Market Rates before the ON RRP

	EFFR	RPR	EDR	CPR
Panel A: Autoregressive terms (sum)				
EFFR	0.911	0.112	0.226	0.164
	(0.00)	(0.26)	(0.00)	(0.03)
RPR	0.018	0.803	0.002	-0.022
	(0.13)	(0.00)	(0.88)	(0.23)
EDR	-0.002	0.045	0.739	0.005
	(0.97)	(0.59)	(0.00)	(0.94)
CPR	0.028	0.052	0.047	0.880
	(0.04)	(0.20)	(0.01)	(0.00)
Panel B: Calendar Effects				
15th	1.11	3.93	1.26	1.42
	(0.00)	(0.00)	(0.00)	(0.00)
25th	-0.29	0.70	0.01	0.54
	(0.03)	(0.17)	(0.94)	(0.02)
Month-end	0.79	3.94	1.19	0.71
	(0.00)	(0.00)	(0.00)	(0.06)
Quarter-end	-3.14	-1.06	-4.29	-2.02
	(0.00)	(0.45)	(0.00)	(0.04)

Table 7: Overnight Money Market Rates after the ON RRP

	EFFR	RPR	EDR	CPR
Panel A: Autoregressive terms (sum)				
EFFR	0.823	0.033	0.290	0.333
	(0.00)	(0.83)	(0.06)	(0.00)
RPR	0.102	0.813	0.096	0.084
	(0.00)	(0.00)	(0.00)	(0.00)
EDR	-0.127	0.101	0.416	-0.145
	(0.01)	(0.42)	(0.00)	(0.01)
CPR	0.129	0.126	0.113	0.565
	(0.04)	(0.21)	(0.12)	(0.00)
Panel B: Calendar Effects				
15th	-0.02	1.61	-0.18	-0.24
	(0.87)	(0.00)	(0.28)	(0.27)
25th	-0.08	0.46	-0.22	-0.12
	(0.50)	(0.17)	(0.09)	(0.54)
Month-end	-2.35	2.42	-3.25	-0.37
	(0.00)	(0.00)	(0.00)	(0.15)
Quarter-end	-3.41	1.10	-6.80	-1.05
	(0.00)	(0.37)	(0.00)	(0.02)

Note: Columns represent equations of the model. The sum of autoregressive terms correspond to $\sum \Xi_j$ in the notation of section 4. p-values based on robust (HAC) standard errors are reported in parentheses. Calendar effects are reported in *basis points*. Daily sample runs from December 17, 2008, to September 20, 2013, in Table 6, and from September 23, 2013, to August 28, 2015, in Table 7.

Table 8: Volatility of Rates

	Pre-crisis				ELB			
	EFFR	RPR	LIBOR	CPR	EFFR	RPR	EDR	CPR
σ_ϵ	5.64	5.91	3.94	4.30	1.05	2.38	1.22	1.51
τ	0.116	0.306	0.450	0.316	0.253	0.231	0.440	0.414
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
δ	0.839	0.173	0.180	0.171	0.396	0.385	0.240	0.282
	(0.00)	(0.11)	(0.03)	(0.01)	(0.05)	(0.00)	(0.00)	(0.00)

Table 9: Volatility of Rates within the ELB Period

	Before ON RRP				After ON RRP			
	EFFR	RPR	EDR	CPR	EFFR	RPR	EDR	CPR
σ_ϵ	1.11	2.65	1.27	1.67	0.73	1.40	0.79	0.83
τ	0.212	0.159	0.365	0.383	0.189	0.315	0.458	0.158
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)
δ	0.561	0.327	0.368	0.281	0.191	0.465	0.146	0.681
	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.01)	(0.00)	(0.00)

Note: p-values based on robust standard errors are reported in parentheses. σ_ϵ are reported in *basis points*.

Table 10: Correlations of VAR Residuals

	Pre-crisis			ELB		
	RPR	LIBOR	CPR	RPR	EDR	CPR
Normal times	0.490	0.586	0.614	0.457	0.545	0.373
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Month-end	0.421	0.246	0.341	0.301	0.879	0.395
	(0.04)	(0.47)	(0.22)	(0.19)	(0.00)	(0.37)
Quarter-end	0.348	0.334	0.362	-0.056	0.564	0.360
	(0.30)	(0.23)	(0.32)	(1.00)	(0.03)	(0.29)

Table 11: Correlations of VAR Residuals within the ELB Period

	Before ON RRP			After ON RRP		
	RPR	EDR	CPR	RPR	EDR	CPR
Normal times	0.502	0.546	0.413	0.128	0.612	0.173
	(0.00)	(0.00)	(0.00)	(0.16)	(0.00)	(0.07)
Month-end	0.395	0.596	0.104	-0.291	0.854	0.039
	(0.17)	(0.05)	(0.63)	(1.00)	(0.00)	(0.90)
Quarter-end	0.032	0.595	0.358	-0.489	0.356	0.334
	(0.95)	(0.05)	(0.34)	(1.00)	(0.59)	(0.51)

Note: Correlations with EFFR. p-values based on robust standard errors are reported in parentheses.