

# Pass-Through Efficiency in the Fed's New Monetary Policy Setting

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## **I. Executive Summary**

Our objective is to show how the current setting of U.S.-dollar money markets limits the pass-through effectiveness of the Federal Reserve's monetary policy. We focus on frictions associated with imperfect competition, regulation, infrastructure and other forms of institutional segmentation within money markets.

Empirically, dispersion across money market interest rates is a primary indicator of the level of pass-through inefficiency. We present a new index of rate dispersion in U.S. short-term money markets, the weighted mean absolute deviation of the cross-sectional distribution of overnight-equivalent rates, after adjusting for premia associated with credit risk and term structure. Between the end of 2012 and Dec. 17, 2015, dispersion ranged between 4 basis points and 7 basis points. Immediately after the first pass-through event in the current Fed monetary policy setting, when the interest rate paid by the Fed on excess reserves (IOER) was increased from 25 basis points to 50 basis points on Dec. 17, 2015, dispersion increased by over 10 basis points. Our analysis aims in part to explain how dispersion could continue to rise with future increases in Fed policy rates.

We model the drag on pass-through caused by imperfect competition for bank deposits, given depositors' costs for search, monitoring and attention. We show how the Fed's reverse repurchase (RRP) facility improves the pass-through of changes in Fed policy rates into average wholesale money market rates. In our model, however, this improvement in average pass-through is achieved mainly through the disintermediation of bank deposits. The RRP facility draws some sophisticated investor cash out of bank deposits and into money funds and T-bills. This causes a selection effect by which the clientele for bank deposits shifts toward less sophisticated depositors, reducing the incentives for banks to compete with each other for deposits. As modeled, the average improvement in pass-through comes with reduced pass-through into average bank deposit rates. It is an open question whether, as rates rise, this effect will actually become important.

We also examine the implications for pass-through of new Basel regulations. We show how pass-through efficiency into repo markets is degraded by the supplementary leverage ratio (SLR) rule, which reduces the incentives of bank-affiliated dealers to reserve space on their balance sheets for repo intermediation. We then explain how the liquidity coverage ratio (LCR) rule can raise dispersion in money market rates by reducing the effective supply of safe assets, although we don't expect this effect to be notable until interest rates are higher. We review the pass-through implications of the reform of regulations for money market mutual funds. Finally, we explore improvements in pass-through that could be promoted by enhancements in repo market infrastructure, including more direct trade platforms and broader central counterparties (CCPs).

In summary, we present theoretical, empirical and institutional analyses of pass-through in the Fed's current monetary policy setting. Our main policy-related conclusions are as follows.

1. The RRP facility aids pass-through, although this is achieved most directly by disintermediation, therefore with attendant costs. As usage of the RRP facility rises, the associated costs include lower pass-through of rates to less sophisticated depositors, footprint effects that harm credit monitoring and price discovery and possible financial instabilities. With regards to

the banking sector, we do not see much reason to be concerned about the potential adverse impact on financial stability of a heavily used RRP facility. Our concern rises, however, for the case of securities dealers.

2. SLR harms pass-through, and has already significantly degraded repo market intermediation, a core market function supporting pass-through.
3. LCR may reduce pass-through when rates rise, but this can be mitigated by Fed or Treasury actions to increase the supply of short-term, high-quality liquid assets (HQLA), such as additional supplies of T-bills or some variant of “Fed bills.”
4. The recent and ongoing regulatory reform of money market mutual funds increases rate dispersion and reduces pass-through by increasing the demand for government paper relative to private paper. These effects can be partly offset by an increase in the supply of T-bills.
5. Improvements in repo market infrastructure, such as a broad repo central counterparty and broadly accessible trading platforms, could significantly improve pass-through to repo markets, and could free a significant amount of “high-rent” space on the balance sheets of large regulated dealers. An alternative would be to modify the SLR rule insofar as its application to U.S. government securities repos.
6. Many of these effects are likely to strengthen as the Fed raises its policy rates. Moreover, it is likely that the take-up at the Fed’s RRP facility will increase significantly once rates rise.

An important caveat is that our analysis focuses almost exclusively on pass-through and rate dispersion in money markets. We do not provide a full analysis of the monetary policy setting. In particular, we have largely set aside issues of financial stability, which is likely to have been improved by both the LCR and money market fund reform.

## **II. Introduction**

In perfect money markets, efficiency is obtained by equating marginal rates of substitution for supplying and receiving funding across all market participants. Uses of funding that offer the highest net present value would thereby get effective priority for funding over uses of funds that offer inferior gains. Funding would be obtained from the most efficient sources, those savers with the lowest value for holding cash. Gains from trade are thus maximized. A necessary condition for perfect money markets is that any change in the Fed's policy rate is passed through, one for one (net of credit and term spreads), to all money market rates.

Given technological matching and contracting frictions between borrowers and lenders, marginal rates of substitution among money market participants must differ somewhat in practice. Perfect competition among financial intermediaries and the absence of regulatory and other institutional impediments would then bound rate dispersion by the marginal real cost of intermediation. In the actuality of imperfect competition and institutional or regulatory market segmentation, however, there is even greater dispersion in rates. The causes and degree of this dispersion are our main policy concerns.

By raising the interest rate that it offers to banks on their excess reserves (IOER), the Fed can achieve essentially any desired average for the cross-sectional distribution of money market rates. Dispersion around this average signals a social cost. With high rate dispersion, there is also a political-economic cost to the Fed through the potential for suggestions that its policy framework favors banks, who would be earning "excessive" interest on their Fed deposits, relative to money market rates offered to others for similar cash investments. While it may be argued that pass-through frictions improve credit provision by allowing higher net interest margins for banks, thus improving bank profitability, there are likely to be more efficient channels for "subsidizing" credit provision.

In the current U.S. monetary policy setting, pass-through efficiency is determined mainly by the degree to which intermediaries compete for cash investments. Competition is dampened by investor costs for

search, credit monitoring, and attention, and by various institutional forms of market segmentation. Pozsar (2016a) maps the complex set of institutional arrangements by which specific groups of market participants are blocked from direct trade with each other, so that funding must flow by relatively intricate and restricted channels from ultimate lenders to ultimate borrowers. At each step along the path, frictional wedges increase dispersion and reduce pass-through efficiency.

We model the effect on pass-through of the introduction by the Fed of an RRP facility that is accessible to some subset of sophisticated cash investors. Whenever the RRP rate is strictly below the market-clearing T-bill rate (after adjusting for term premia), the RRP facility is not used and the equilibrium is unaffected. Whenever the RRP rate is strictly above the market-clearing T-bill rate, however, sophisticated cash investors prefer the RRP rate unless some bank offers an even higher rate. This latter case can occur if the supply of T-bills is sufficiently low. The RRP rate is automatically a floor on the rates earned by those investors with access to the RRP. (The RRP rate and the market-clearing T-bill rate can be the same in equilibrium, for a non-trivial set of parameters.) Changes in the free float of T-bills, caused for example by the U.S. Treasury's cash management or the heavy sales of quasi-sovereigns in early 2016, are therefore important to the volume of RRP take-up and to the effectiveness of RRP as a mitigator of rate dispersion. Likewise, changes in the demands by investors for money-market products, such as the increased demand for T-bills arising from the recent regulatory reform of money market funds, and changes in the incentives of banks to supply deposits, can also affect RRP take-up and rate dispersion.

Among other results, we show that the RRP facility improves average pass-through efficiency, mainly via disintermediation of banks. There is a natural selection effect, however, by which RRP disintermediation pulls more sophisticated cash investors away from bank deposits, encouraging banks to exercise more of their market power over less-sophisticated depositors, thus reducing average pass-through to bank deposit rates, at least in our simple model. The extent to which this will happen in reality is uncertain until rates are higher.

We model these effects with an extension of the search-cost model of Stahl (1989). In our base-case model, each bank is assumed to have such a large stock of central bank deposits that the net interest margin on gathering additional deposits is IOER less the mean rate paid to depositors. (We adjust IOER by deducting Federal Deposit Insurance Corp. (FDIC) fees and regulatory shadow prices.) Without RRP, wholesale cash investors in our model compare the deposit rates offered by banks with the market-clearing rate on a safe competitively traded instrument, which we take to be Treasury bills. Cash investors have a strong “transactions preference” for holding at least some non-zero amount of bank deposits. Each cash investor optimally chooses its amounts of bank deposits and T-bills based on the respective rates offered on these instruments. “Fast” cash investors (those with no search costs) pick the highest bank deposit rate available across  $N$  of the banks. In equilibrium, the competitiveness of deposit rates depends on the fraction of fast investors, the number  $N$  of banks competing for the deposits of a given fast investor, and the costs to slow investors for search and monitoring. Banks choose a profit-maximizing distribution of deposit rates. Because of imperfect competition, banks make a trade-off between volumes and rates, maximizing the product of volume and average net interest margin, net of fees and regulatory shadow prices. In equilibrium, the strategies of slow investors lead them to accept the first deposit rate they are offered.

We extend our model to incorporate the effect on pass-through of limited attention by slow cash investors, in light of the strong empirical evidence of asymmetry in deposit rate responses to market conditions.<sup>1</sup> When T-bill or fed funds rates move down, banks quickly reduce the deposit rates they offer. When T-bill or fed funds rates move up, however, banks are much slower to adjust the rates they offer on money market deposit accounts (MMDAs) and six-month certificates of deposit (CDs). Indeed, there is essentially no upward adjustment of these deposit rates within the first week, as shown by Driscoll and Judson (2013), and additional partial adjustment continues for months afterward. As in Yankov (2014), our model shows that banks exploit the limited attention of their deposit customers,

further dampening pass-through when policy rates rise. Additionally, we show that the limited pass-through into deposit rates dampens pass-through into other money market rates, such as those for T-bills or tri-party repo (TPR). Raising the IOER leads to a rise in the spread between IOER and deposit rates as well as the spread between IOER and T-bill rates; a theoretical result that accords with considerable empirical evidence. We show that the RRP mitigates the pass-through friction associated with this inattention effect, but again the benefit to average pass-through is achieved through the disintermediation of fast-investor bank deposits. We show that adding the RRP facility, or increasing the RRP rate offered by an existing facility, tends to reduce the pass-through of IOER into average bank deposit rates. We also show that the take-up at the RRP will rise when the IOER rate rises.

We then further extend our model so as to treat the impact of the liquidity coverage ratio (LCR) rule on pass-through. The LCR requires banks to have enough unencumbered high quality liquid assets (HQLA) to meet a 30-day stressed liquidity outflow scenario. The amount of HQLA required to meet LCR is higher for banks funded with non-operating wholesale deposits than for banks that are more heavily funded by operating deposits and retail deposits (for example, J.P. Morgan should be advantaged here, relative to Morgan Stanley). When measuring a bank's effective HQLA holdings for purposes of meeting LCR, different types of HQLA are classified into "levels" according to liquidity. The regulation assigns a higher HQLA weight to Level-1 HQLA, such as Treasuries and Ginnie Mae (GNMA) mortgage bonds, than to Level-2 securities such as Fannie Mae/Freddie Mac (FNMA/FHLMC) mortgage bonds or agency debt. The LCR rule can distort spreads between the rates paid on different levels of HQLA, because of their different treatments under the rule. In particular, if there is a scarcity of HQLA, LCR will cause the rate spread between Level-1 HQLA and Level-2 HQLA to rise. In examining these spreads, however, we find that the LCR does not currently appear to be doing so. Because of this empirical fact, we doubt that the LCR rule is currently impinging on the supply of HQLA or has much effect on pass-through.

The LCR could come to affect equilibrium, however, when interest rates rise. This would raise all interest rates, but with a smaller rate impact for HQLA. That is, as LCR impinges on the supply of HQLA, rate dispersion rises, with attendant pass-through concerns. In this situation, the Fed or Treasury could improve pass-through by increasing the supply of safe short-term assets. The Treasury could issue more T-bills. For its part, the Fed could purchase riskier or longer-term assets in exchange for safer short-term assets. It could do this directly by purchasing, for example, agency mortgage-backed securities (MBS), paying with reserves. The Fed could also increase the supply of safe short-term assets by conducting reverse repos against agency MBS through the RRP facility. Alternatively, the Fed could address this concern by purchasing agency MBS, funded by some form of “Fed bills.” Garratt, Martin, McAndrews and Nosal (2015) propose a variant of Federal Reserve bills called “segregated balance accounts.”

We show that the SLR has significantly reduced pass-through efficiency into the repo market, a core segment of U.S. dollar money markets. The SLR requires U.S. globally systemically important bank holding companies to have capital equal to or greater than 5 percent of their total assets, regardless of the risk composition of the assets. Assuming the SLR is a binding constraint (which we show is consistent with current market behavior), a large U.S. bank-affiliated dealer conducting an additional \$100 of Treasury repo intermediation requires the same \$5 of incremental capital that would be required for intermediating \$100 of riskier assets, for example real estate loans. Given this lack of regulatory differentiation of asset risk, if the bank were to intermediate risk-free repos rather than riskier assets, the dealer would make its legacy creditors safer, causing a net transfer of market value from shareholders to legacy creditors. We show that bid-ask spreads for repo matched-book intermediation must be widened dramatically to overcome this wealth transfer. This is a variant of the “debt overhang” concept of Myers (1977). We explain that the impact of SLR on the break-even bid-ask spread for repo intermediation is approximately  $2CS$ , where  $C$  is the SLR (now 5 percent) and  $S$  is the average credit spread of the unsecured bail-in-able debt of the major dealers, currently about 120 basis points. The SLR impact on required repo intermediation spreads is thus currently about 12

basis points. In response to SLR, major U.S. bank-affiliated dealers have indeed dramatically widened their bid-ask spreads in the U.S. government securities repo market. A proxy for this spread is the difference between the financing rates paid by nonbank-affiliated dealers in the general collateral finance (GCF) repo market, relative to the financing rates paid by bank-affiliated dealers in the TPR market. In the last two years, this spread has increased from under 4 basis points to about 17 basis points, an impact similar in magnitude to that predicted by our rough theoretical estimate of the SLR impact.<sup>2</sup> This large dispersion in financing rates for essentially the same two (extremely safe) money-market instruments, GCF repo and TPR, signals a significant market distortion. Data shown by Martin (2016) implies that GCF repo volumes have declined by about 30 percent since 2012, and that the amount of cash financing obtained in this market by nonbank-affiliated dealers from bank-affiliated dealers has declined by about 80 percent from 2013 to the end of 2015. In the last quarter of 2015, the three-month Treasury-secured repo rates paid by nonbank dealers were higher even than the three-month unsecured borrowing rates paid by banks (LIBOR).

The rate dispersion caused by SLR might be partially cured by the RRP facility, which puts a floor on TPR rates, given that money market funds have the option to invest in TPR or RRP, which are very close substitutes. On the other hand, flooring TPR rates makes repo intermediation even less profitable for bank-affiliated dealers, and should reduce the quantity of their repo intermediation even further. This in turn could drive GC repo rates up further, but should not drive them much higher than IOER, because banks could then directly step in to offer cash to GC borrowers. (The bank subsidiaries of the largest bank holding companies currently have a 6 percent SLR requirement, a bit higher than the SLR for their consolidated bank holding company.) Recently, GCF treasury repo rates have actually been above IOER at quarter-ends, due to the SLR-induced “window dressing” of foreign bank quarter-end balance sheets (U.S. monitoring of SLR is based on average daily balance sheets). Overall, it is not clear whether the existence of the RRP mitigates or exacerbates the effect of SLR on rate dispersion in the repo market.

We also discuss the impact of money market fund reform on pass-through. Beginning October 2016, institutional prime money market funds must maintain a floating net asset value. Investors in these funds will also face liquidity fees and redemption gates. These restrictions will not apply to government-only money funds. These reforms reduce systemic risk but raise dispersion, because the rule changes drive up the demand for government assets such as T-bills relative to private assets such as bank deposits and short-term commercial paper. The rule change can also reduce the pass-through of increases in the IOER rate to money market rates by limiting the supply of deposit alternatives, and by raising the cost of meeting LCR, whenever it is binding, given the impact of MMF demand on T-bill rates and HQLA supply.

Improvements in the infrastructure of the U.S. repo market could improve pass-through efficiency. The drag on repo intermediation caused by SLR-related costs for access to dealer balance sheets could be mitigated if ultimate cash investors could trade directly with ultimate collateral providers, achieving better integration of rate formation in the tri-party, bilateral, and GCF repo markets. Direct or multilateral repo trading platforms could directly connect a wider set of cash lenders and collateral providers.<sup>3</sup> The consequent reduction in rate dispersion would be unambiguous, unlike the effect of the RRP facility. Our conversations with managers of money-market mutual funds suggest that these funds are indeed establishing relationships with new types of counterparties and are open to new trading venues such as “direct repo” platforms. At the same time, money fund managers are wary of shifting significantly away from traditional dealer counterparties in the TPR market, given the long-run importance of those relationships relative to other counterparties (including the RRP) that may not be as stable over the long run.

Another approach to reducing the wedge in repo markets caused by the SLR is the development of a broad-based central counterparty (CCP). As we explain in Section VIII, this would allow banks to more effectively net their long and short repo exposures, reducing the balance sheet space required for repo intermediation, thus lowering the impact of SLR-induced debt overhang on their bid-ask spreads.

So far, attempts at a broad-based U.S. repo CCP have failed. One entrant, LCH, seems to have abandoned its efforts. The Fixed Income Clearing Corp. (FICC), an existing U.S. interdealer repo CCP, has thus far been unable to obtain the liquidity backstops necessary to extend clearing memberships to a broader set of nondealers, but proposes to offer this expanded service beginning in 2017.

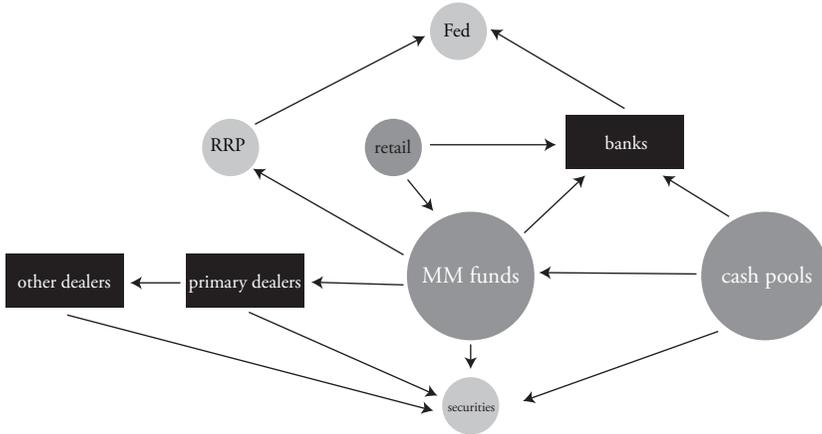
The paper is organized as follows. Section III reviews the main sources of segmentation in the current institutional setting of U.S. money markets. Section IV introduces a new index of rate dispersion and discusses its empirical behavior. Section V models the implications for rate dispersion of imperfect competition and frictional costs associated with depositor search, monitoring, and attention. We focus throughout on the pass-through implications of the RRP facility. Section VI provides an analysis of the pass-through implications of the SLR rule and the LCR rule. We use debt-overhang theory and empirical evidence to show that the SLR has dramatically increased the cost to dealer shareholders for allocating balance-sheet space to repo intermediation. We show that the resulting adverse impact on repo market liquidity is exacerbated by end-of-quarter balance-sheet “window-dressing.” Section VII reviews the pass-through implications of the regulatory reform of money market mutual funds. Section VIII discusses the dependence of pass-through on repo market infrastructure, focusing on the role of trade platforms, central counterparties, and tri-party clearing banks. Section IX offers concluding remarks.

### **III. Market Segmentation**

The pass-through effectiveness of U.S. monetary policy is limited in several important ways by the regulation and infrastructure of wholesale money markets. Some segments of borrowers and lenders, both intermediate and final, are not as accessible to each other as they would be in an efficient market. Although funding can eventually flow through the network of market participants from any point to any point, some direct links are missing and others have frictions that significantly widen bid-ask spreads.

Figure 1 illustrates some typical cash investors and their active investment choices in current U.S. money markets. Obviously, this

**Figure 1**  
**Typical Active Choices of Selected Money-Market Cash Investors**



Notes: Arrows indicate the direction of cash investment. Here, “Fed” indicates central bank liabilities, in the form of either Federal Reserve deposits or reverse repurchase agreements. “RRP” indicates the Fed’s reverse repurchase facility. Figure 11 of Potter (2016) shows that the vast majority of RRP investments have been made by money market mutual funds (“MM funds”). “Securities” indicates T-bills and other tradable money-market instruments such as commercial paper. “Retail” refers to smaller or less sophisticated depositors. “Cash pools” refers to buy-side wholesale cash investors such as asset managers and corporations. The largest primary dealers are bank affiliated, thus subject to Basel balance-sheet regulations. The “other dealers,” who can be treated as inclusive of hedge funds and other liquidity providers, obtain secured funding from primary dealers. Some major cash investors that are not shown, such as securities lenders, federal agencies, and foreign central banks, are discussed in the text.

schematic is far from exhaustive and suggests only a small selection of broad categories of investors, but may be useful in explaining some of the key sources of market segmentation. Among the market participants shown, only banks are able to hold balances in an account at the Fed that earns IOER. The transmission of changes in IOER into money market rates is therefore limited by the degree to which banks compete with each other. Money funds have effective indirect access to federal reserves through the RRP, but at a lower interest rate. Typical cash pools such as operating companies and many types of asset managers do not have direct or indirect access to federal reserves. So, when IOER is increased, cash pools and money fund investors benefit from higher deposit rates to the extent that banks compete for their deposits, and benefit from higher returns on securities such as T-bills to the extent that substitution between bank deposits and other instruments shifts the demand curve for securities upward.

Major money-center banks and their primary dealer affiliates are in principle well positioned to efficiently connect funding markets.

In unsecured money markets, banks are directly accessible to a wide range of potential primary borrowers (each other, their commercial-lending clients such as operating companies, and the Fed) and lenders (again including each other, corporate and institutional depositors and commercial-paper investors). As for secured funding markets, the major securities dealers are natural hubs. They intermediate securities financing markets whose active participants include other dealers, hedge funds, money-market funds, and securities lending firms. (The key securities financing markets are those for repos and securities lending agreements.) Dealers also provide two-way markets in money-market securities such as T-bills, commercial paper, and Federal Home Loan Bank discount notes. Primary dealers are privileged by their access to funding in the TPR market from money market funds and from the cash collateral collected by securities lenders. These cash investors have many other investment options, but prefer to maintain a significant fraction of their portfolio in the tri-party market, which is a steady source of safe assets.

In addition to major private-sector cash investors, significant official-sector or quasi-government investors include government sponsored enterprises (GSEs), foreign central banks, and sovereign wealth funds. Foreign central banks own U.S. cash assets as part of their foreign-exchange reserve portfolios. Relative to other cash investors, foreign central banks tilt their portfolios towards government securities such as T-bills, and tend to be less price sensitive in the short run. Foreign central banks also invest cash at the Fed in the form of reverse repurchase agreements, in a facility known as the “foreign repo pool.”

The GSEs are active investors in both the repo market and the federal funds market. Through the month, the GSEs receive cash payments from homeowners. At the end of the month, the GSEs pay this cash to MBS holders. Because of this cash cycle, GSE cash balances increase over the course of each month, and then drop towards the end of the month.<sup>4</sup> The GSEs invest their cash into both the TPR market and the federal funds market. In recent years, as explained and modeled by Bech and Klee (2011) and Garratt, Martin, McAndrews and Nosal (2015), the GSEs have lent to foreign banks in the federal funds

market, who then invest in IOER, earning the consistently positive spread between IOER and federal funds. Foreign banks, rather than U.S. banks, have been active in earning this spread because U.S. banks are subject to an FDIC fee in this transaction.

In practice, money market funds and other large cash pools tend to invest in bank deposits in the eurodollar market.<sup>5</sup> The funding that banks obtain in the eurodollar market is an effective substitute for federal funds (interbank deposits), but is preferred by banks, because eurodollar deposits are not subject to reserve requirements, and in light of the FDIC insurance fee applied to domestic bank liabilities. Because of this, the federal funds effective rate (FFER) has become an unreliable gauge of the overnight unsecured wholesale cost of funds for U.S. banks.<sup>6</sup> Accordingly, the Fed has developed an alternative benchmark, the overnight bank financing rate (OBFR), which relies heavily on eurodollar transaction rate data.<sup>7</sup>

From Figure 1, one can see that changes in IOER would be passed through to money markets one-for-one (after correcting for credit and term premia) provided that: 1) banks and primary dealers are perfectly competitive and 2) banks and dealers perceive no costs to their shareholders for adjusting their balance sheets. Neither condition applies. In Sections V and VI, we focus on several impediments to pass-through efficiency:

1. Imperfect competition by financial intermediaries.
2. Search, relationship, monitoring, and attention costs on the part of some cash investors.
3. Capital and liquidity regulation for banks and bank-affiliated dealers, particularly the SLR rule and the LCR rule.

#### **IV. An Index of Rate Dispersion**

This section explores the behavior of a new index of cross-sectional rate dispersion in short-term U.S.-dollar money markets. We observe strongly positive and time-varying dispersion. We show that dispersion has been higher during the financial crisis, on quarter-ends and after the introduction of tighter balance-sheet regulations.

Our dispersion index is designed with the idea that it would be zero in a frictionless market without measurement noise, so that its actual level ideally reflects cross-sectional variation in rates caused only by pass-through frictions. In practice, however, our dispersion index suffers from measurement error and a lack of available data in several areas. While our dispersion index is crude, it may be useful as an empirical gauge of pass-through efficiency.

In order to construct our dispersion index, we collected rate and volume data on a range of shorter-term money-market instruments: jumbo time deposits, commercial paper, GCF repos, TPRs, eurodollar deposits and T-bills of two different maturity “buckets” (one to 10 days, and 11 to 40 days), over the period Jan. 1, 2002 to June 30, 2016. In several cases, missing data are substituted with approximations. Details and sources are provided in Appendix A.

We let  $y_{i,t}(m)$  denote the rate at time  $t$  on instrument  $i$ , maturing in  $m$  days. We first adjust the rate to remove term-structure effects, obtaining the associated “overnight-equivalent” rate as

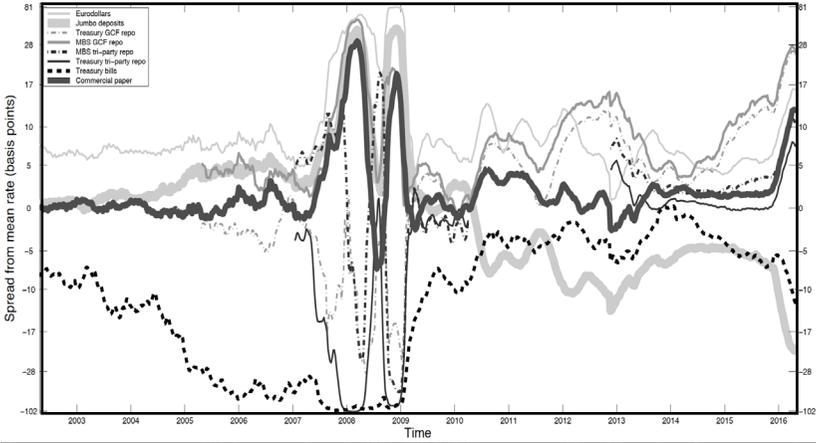
$$\hat{y}_{i,t} = y_{i,t}(m) - (OIS_t(m) - OIS_t(1)), \quad (1)$$

where  $OIS_t(m)$  is the  $m$ -day overnight index swap (OIS) rate at time  $t$ . For unsecured instruments other than jumbo deposits, in order to avoid significant credit effects, we use only overnight rates. For jumbo deposit rates, in addition to adjusting for term, we also adjust for credit spreads by subtracting the spread between LIBOR and OIS associated with the term of the instrument.

A selection of the resulting overnight-equivalent rates, adjusted for term and credit spreads, is shown in Chart 1. (For illustrative clarity, some subsets of similar rates are combined.) Each instrument's rate is plotted with a line thickness proportional to the average outstanding quantity of the instrument over the sample period over which the rate data are available. For better visualization, the vertical axis is rescaled nonlinearly, as explained in the chart notes.

Armed with the adjusted rates and volumes, we compute the dispersion index  $D_t$  at day  $t$  as the weighted mean absolute deviation of the cross-sectional adjusted rate distribution on that day. That is,

Chart 1



Notes: The cross-sectional distribution of a selection of overnight-equivalent money-market rates, shown as rolling 120-day lagging averages. The underlying rates included in this analysis are as described in the text and legend, and are shown net of simple adjustments for credit and term premia. The line weight of a given rate is proportional to the average outstanding quantity of the instrument over the period in which it is present in the sample. The vertical scale is “stretched” near median levels, relative to tail levels, with a nonlinear rescaling given by the students- $t$  distribution with 3 degrees of freedom. Thus, the equally spaced tick marks on the vertical axis are separated by an unequal number of basis points, as shown. (This plot is extremely preliminary).

$$D_t = \frac{1}{\sum_i v_{i,t}} \sum_i v_{i,t} |\hat{y}_{i,t} - \bar{y}_t|, \quad (2)$$

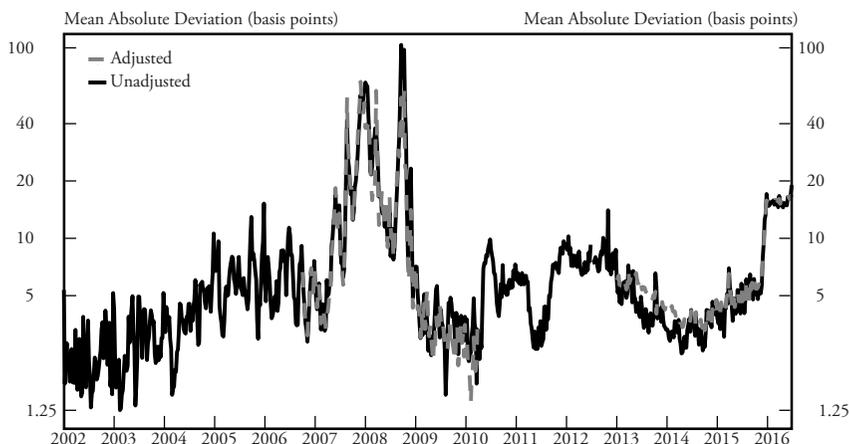
where  $v_{i,t}$  is the estimated outstanding amount of this instrument on day  $t$ , in dollars, and  $\bar{y}_t$  is the volume-weighted mean rate, defined by

$$\bar{y}_t = \frac{\sum_i v_{i,t} \hat{y}_{i,t}}{\sum_i v_{i,t}}.$$

This index has a negative bias, relative to dispersion across all actual money-market transactions rates, because it does not incorporate the heterogeneity of individual transaction rates within each segment of money markets.

Chart 2 shows the variation of the dispersion index  $D_t$  over the sample period. As shown, dispersion increases in the run-up to the crisis, peaking in late 2008. Dispersion has decreased since the crisis, but remains higher than its pre-crisis level. Table 1 provides the results of a time-series regression of dispersion on various explanatory variables: the Markit CDX index (as a measure of crisis severity);

Chart 2



Notes: The dispersion index  $D$ , the weighted mean absolute deviation of the cross-sectional distribution of selected money-market rates at time  $t$ . The underlying overnight-equivalent rates included in this analysis are as described in the text, and are net of simple adjustments for credit and term premia described in the text. The vertical axis is on a logarithmic scale. The adjusted dispersion index, shown in gray and available only during a subperiod due to data gaps, further adjusts each unsecured overnight-equivalent rate by subtracting the spread  $u_t - s_t$  between an unsecured overnight “benchmark” rate  $u_t$  and a secured overnight “benchmark” rate  $s_t$ . For  $u_t$ , we use the average of the eurodollar rate and FFER. For the secured rate  $s_t$ , we use the average of the rates on treasury GCF repo and Treasury tri-party repo.

the target federal funds rate (which, in the post-2008 period, is set at the middle of the Fed’s target range for FFER); an end-of-quarter dummy; and a post-2014 dummy. The first of these dummies captures the effect of the quarter-end window-dressing of bank balance sheets, described in Section VI. The second dummy picks up the change in dispersion since 2014, after which several significant new bank regulations came into force, notably SLR and LCR. As illustrated, dispersion has climbed almost continually since 2014. The three columns in Table 1 differ in the lag structure used to adjust standard errors. All of the columns show that dispersion is high during the crisis, is positively related to the level of rates and is higher at quarter-ends and after 2014. We will return to each of these points with more detailed analysis.

Ideally, we would also adjust the unsecured overnight-equivalent rates by the spread between a benchmark unsecured bank-quality overnight rate and an overnight risk-free secured benchmark rate. Due, however, to the lack of a suitable one-day secured benchmark

Table 1

	1	2	3
	$D_t$	$D_t$	$D_t$
CDX Index	0.00139*** (12.68)	0.00139* (2.47)	0.00139** (2.75)
Fed Funds Target	0.0313*** (12.27)	0.0313*** (3.49)	0.0313** (2.94)
1(Quarter End)	0.0247 (1.82)	0.0247* (2.37)	0.0247** (2.80)
1 (Post 2014)	0.0499*** (4.82)	0.0499** (3.02)	0.0499** (2.61)
Intercept	-0.0960*** (-6.91)	-0.0960 (-1.74)	-0.0960*** (-1.94)
$N$	609	609	609
Error Structure	No lag	1 quarter lag	1 year lag

$t$  statistics in parentheses

\*\*\*  $p < 0.001$

\*\*  $p < 0.01$

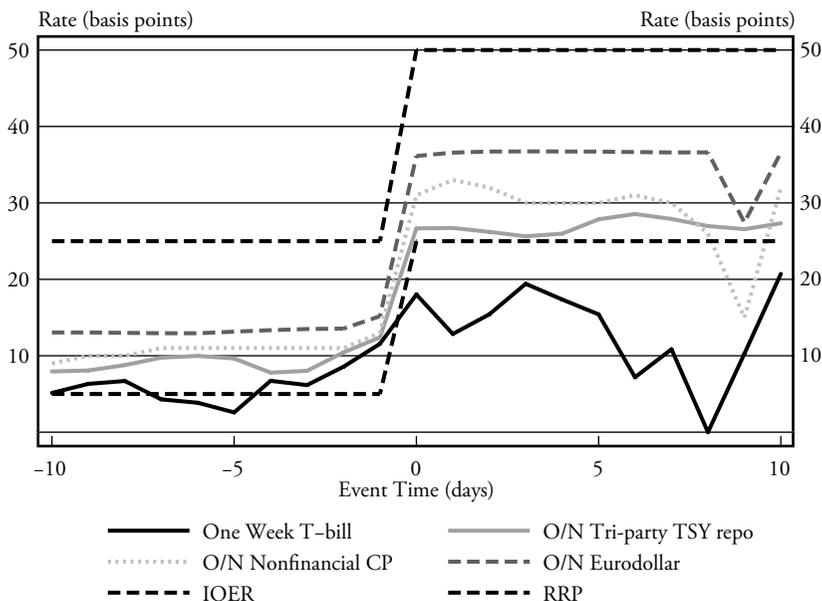
\*  $p < 0.05$

Notes: The results of text generalized-least-squares time-series regressions of dispersion  $D_t$  on the Markit CDX index, the target federal funds rate, an end-of-quarter dummy, and a post-2014 dummy. After the introduction of IOER in 2008, the target federal funds rate is set at the middle of the Fed's target range for FFER. Each regression is associated with an indicated error structure for purposes of determining GLS covariances. The number  $N$  of observations is also indicated.

rate that is available for the entire sample period, nor the data required to construct such a benchmark, we are unable to make this final adjustment to overnight unsecured rates. Because of a notable flight to quality during the financial crisis, our dispersion index is therefore overstated during the crisis. Chart 2 and Appendix A show the effect of making this additional adjustment for a subperiod, including the financial crisis, for which we have enough data to construct reasonable proxies for an overnight bank-quality unsecured rate benchmark and an overnight Treasury-secured repo rate benchmark. This adjustment reduces average dispersion during the crisis, but there is still a substantial increase in the adjusted dispersion index during the financial crisis.

Chart 3 shows the impact on a selection of money market rates of the unique historical “pass-through event” in the current monetary policy setting. This event occurred Dec. 17, 2015, when IOER was raised from 25 basis points to 50 basis points (effective Dec. 18), and the rate paid by the Fed's RRP facility was increased from 5

Chart 3



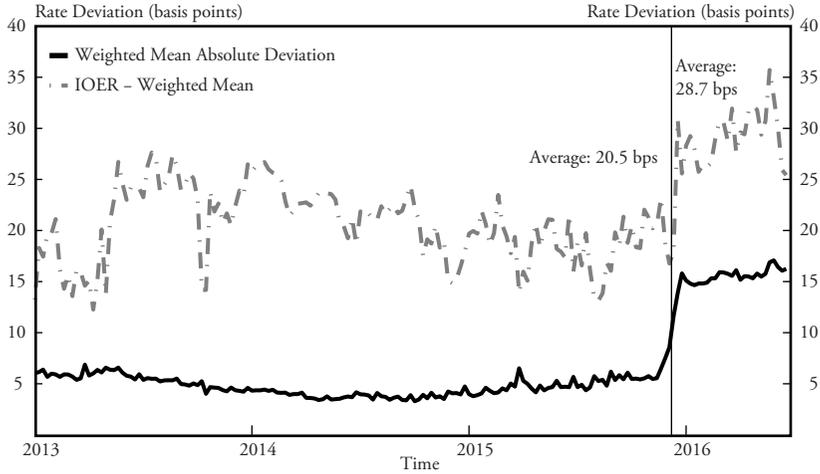
Notes: The impact on various money market rates of the unique historical “pass-through event” in the current monetary policy setting, which occurred Dec. 17, 2015, when IOER was raised from 25 basis points to 50 basis points (effective Dec. 18), and the Fed’s RRP rate was increased from 5 basis points to 25 basis points. The event time shown on the horizontal axis is measured in days from Dec. 17. The plotted rates, in basis points, are IOER, the Fed’s RRP rate, the one-week T-bill rate (on a money-market basis), the overnight eurodollar deposit rate, the rate paid on high-quality (A1/P1) nonfinancial commercial paper, and the average rate on tri-party repos collateralized by U.S. Treasuries.

Sources: Federal Reserve and CRSP.

basis points to 25 basis points. Chart 4 shows that dispersion clearly increased markedly when the Fed’s policy rates jumped. As shown in Chart 3, pass-through of IOER into the eurodollar market is relatively quick and nearly one for one, given the potential for arbitrage between eurodollar deposits and federal reserves that are not subject to an FDIC fee.<sup>8</sup> Pass-through into overnight nonfinancial commercial paper rates, overnight tri-party treasury repo rates, and one-week T-bill rates is successively more and more dampened by market frictions. Chart 4 also plots the difference between IOER and the weighted mean money market rate. While IOER increases by 25 basis points at this event, the weighted mean money market rate increases by only 16.8 basis points, indicating incomplete pass-through.

Chart 3 also shows some year-end effects, eight and nine days after the policy rate changes, that are likely due to the window dressing of bank balance sheets, discussed in Section VI.ii.

Chart 4



Notes: The adjusted dispersion index  $D_t$ , the weighted mean absolute deviation of the cross-sectional distribution of selected money-market rates at time  $t$ , is plotted in solid. The difference between IOER and the weighted mean money market rate is plotted in dashed line. The chart also indicates the mean value of the IOER minus weighted mean rate prior to Dec. 17, 2015, and after this date. The underlying overnight-equivalent rates included in this analysis are as described in the text, and are net of simple adjustments for credit and term premia described in the text. The adjusted dispersion index shown is based on removing from each unsecured overnight-equivalent rate the spread  $u_t - s_t$  between an unsecured overnight “benchmark” rate  $u_t$  and a secured overnight “benchmark” rate  $s_t$ , as described in the text. The chart shows a pronounced increase in dispersion with the unique pass-through event of the Fed’s new monetary policy setting, at the increase in IOER from 25 basis points to 50 basis points on Dec. 17, 2015 (effective Dec. 18). The time of this event is marked with a vertical line. The RRP rate was simultaneously increased from 5 basis points to 25 basis points. The chart also shows that pass-through in this event is less than one-for-one, as the weighted mean rate rises less than the increase in IOER.

## V. Imperfect Competition and Pass-Through Dispersion

This section presents a simple model of imperfect competition for bank deposits in an economy with central bank reserves and alternative wholesale money market investments. Prior equilibrium models of imperfect competition for deposits by banks, including those of Armenter and Lester (2015), Yankov (2014), and Garratt, Martin, McAndrews and Nosal (2015), take different modeling approaches. Our model is designed to capture implications for rate dispersion across different segments of money markets. After solving the most basic version of our model, we introduce a reverse repurchase facility (RRP) to examine its pass-through implications. We then consider the implications of depositor attention costs for weakened and asymmetric pass-through. In Section VI, we extend our analysis to the implications for pass-through of the Liquidity Coverage Ratio (LCR) and the Supplementary Leverage Ratio (SLR). Appendix B contains technical supporting results and proofs.

***V.i. Basic Model Without RRP***

We begin with a basic search-based model of imperfect competition, in the spirit of Stahl (1989). Our market participants are a finite number  $N$  of banks and a continuum of cash investors whose total mass is without loss of generality set to 1. Cash investors are of two types, “fast” and “slow,” forming respective fractions  $\mu$  and  $1-\mu$  of the investor population. Slow investors have  $w$  per capita to invest, before search and monitoring costs, and invest only in bank deposits. Fast investors are sophisticated cash pools that costlessly scan the rates offered by the  $N$  banks, determine the highest of these rates  $r^* = \max\{r_1, \dots, r_N\}$ , compare this deposit rate  $r^*$  with that of other wholesale money market rates, and then solve the associated portfolio problem

$$\begin{aligned} \max_{b,f,t} & b(1 + r^*) + f(1+h) + t(1 + g) + K \log(b) + k \log(f+t) \\ & \text{subject to } b + f + t \leq W, \end{aligned}$$

where  $b$ ,  $f$ , and  $t$  are the amounts of funds placed in bank deposits, money market funds (MMFs), and T-bills, respectively; where  $W$  is a fast investor’s total (per-capita) funds to be placed; and where  $h$  and  $g$  are the equilibrium interest rates on MMFs and T-bills, respectively. The logarithmic utility terms, those with coefficients  $K$  and  $k$ , are designed to capture transactional convenience benefits, above and beyond interest income. Each fast investor thus has a strong marginal transactional preference to hold at least small amounts of bank deposits and of T-bills or money market funds. The coefficients  $K$  and  $k$  are calibrated so that marginal transactional benefits decline rapidly, relative to investment benefits, as the amounts held increase. We ignore the credit risk of bank deposits, which could be approximated with additional coefficients. We let  $D(r^*; g, h)$  denote the explicit solution to a fast investor’s optimal choice for the amount  $b$  to invest in bank deposits, given the available rates  $r^*$ ,  $g$  and  $h$ .

A slow investor first checks the rate  $r_i$  offered by some bank  $i$ , and then considers whether to incur a frictional cost  $c > 0$  to compare  $r_i$  with the rate offered by some other bank. Any number of banks can be successively visited, before the investor stops searching and chooses the bank with the highest of the observed rates. The cost  $c$  of checking

the rate offered by each successive bank reflects the costs of search, delay, account setup, relationship frictions, and monitoring. Slow investors deposit  $w$  per capita in their chosen bank. It makes no difference whether the slow depositors choose the first bank at random (independently, each bank with probability  $1/N$ ), or have a deterministic “relationship bank” from whom the first offered rate is obtained, with equal investor masses of  $(1 - \mu)/N$  per relationship bank.

Search, delay, and monitoring costs play a role even in wholesale deposit rates. For example, Ashcraft and Duffie (2007) and Afonso and Lagos (2015) show strong empirical evidence of rate dispersion induced by search and relationship costs in the fed funds (interbank) market.<sup>9</sup> These studies (based on data from the pre-IOER era) show that the deposit rate transacted between two banks at a given minute of the day depends significantly on the current intraday reserve balances of each of the two banks at that minute and on the relative centralities of the two banks in the market, as represented by their normal transactions volumes. These effects would not be present in a competitive market—all trades at a given point of time would be conducted at the same rate, after correcting for credit risk.

In any equilibrium, a bank offers deposit rates drawn from a non-atomic cumulative distribution function  $F$  whose support is some interval  $[\underline{r}, \bar{r}]$ . The solution to “Pandora” search problems of the type faced by slow investors implies that each slow investor accepts the first rate it is offered if and only if that rate is no lower than  $r_F - c$ , where  $r_F = \int r dF(r)$  is the mean deposit rate offered by any single alternative bank.<sup>10,11</sup> Notably, the number of banks plays no role in the slow investor’s decision. The model is easily reinterpreted so that the number  $N$  of banks monitored by any given fast investor is less than the total number of banks in the economy.<sup>12</sup>

Banks can invest customer deposits in loans, bonds, or central-bank reserves. There is a perfectly competitive interbank spot market for reserves. We assume that reserves are so plentifully supplied by the central bank that the interest rate offered on excess reserves (IOER), denoted  $\rho_1$ , determines a constant marginal benefit of collecting additional deposits (Later, we generalize.) We allow for regulatory and other costs for holding deposits such as FDIC insurance fees, so

that the all-in shadow value for raising deposits is some constant  $\phi$ , bounded above by  $\rho_1$  (IOER). Later, we discuss how  $\phi$  is affected by regulations such as LCR and SLR. The marginal benefit of taking deposits at the interest rate  $r$  is thus the net interest margin (NIM)  $\phi - r$ .

In equilibrium, the lowest deposit rate  $\underline{r}$  offered by a bank is the indifference rate  $r_F - c$  of slow investors. The marginal net expected benefit to a bank of deposits taken at any rate  $r$  in the support  $[\underline{r}, \bar{r}]$  of  $F$  must be the same as that at any other rate in the support. If not, the bank would shift probability mass from one support point to another. There is zero probability that the lower support point  $\underline{r}$  is as high as the rate offered by some other bank, so no fast-investor deposits are made at the rate  $\underline{r}$ . These two facts imply the following indifference condition at any supported deposit rate  $r$ :

$$\left[ \mu F(r)^{N-1} D(r; g, h) + \frac{1-\mu}{N} w \right] (\phi - r) = \frac{1-\mu}{N} w (\phi - \underline{r}) \quad (3)$$

The right-hand side is the marginal benefit of quoting at the lowest rate  $\underline{r}$  and collecting  $w$  in per-capita deposits from the mass  $(1-\mu)/N$  of slow investors that check this particular bank first. The left-hand side is the marginal benefit of quoting at an arbitrary point  $r$  in the support of  $F$ , thereby collecting the net interest margin  $\phi - r$  on both the total slow-investor deposit amount  $(1-\mu)w/N$ , and also on the fast-investor amount  $\mu D(r; g, h)$  provided that  $r$  is above the rate offered by all of the other  $N-1$  banks, which occurs with probability  $F(r)^{N-1}$ . Imposing the adding-up constraint that  $F(\bar{r}) = 1$  leads to an explicit solution for  $\bar{r}$ , and thus  $F$ , which depends on the endogenous rates  $g$  and  $h$  on T-bills and MMFs, respectively.

This allows us to close the model by adding market-clearing conditions for money market funds and T-bills. For the simplest version of the model, we assume that MMFs are government funds that invest only in T-bills. Thus, MMFs and T-bills are indistinguishable from the viewpoint of investors, and must offer the same rate  $g$  in equilibrium. The corresponding cumulative distribution function for offered deposit rates is denoted  $F_g$ , reflecting its dependence on the T-bill rate  $g$ .

Given the T-bill rate  $g$ , the total demand for deposits is therefore

$$V(g) = \mu \int_r^{\bar{r}} D(r; g, g) dF_g^N(r) + (1 - \mu)w \quad (4)$$

Given an exogenously supplied face value  $S$  of T-bills, the T-bill rate  $g$  is then determined by equating the market values of T-bills demanded and supplied:

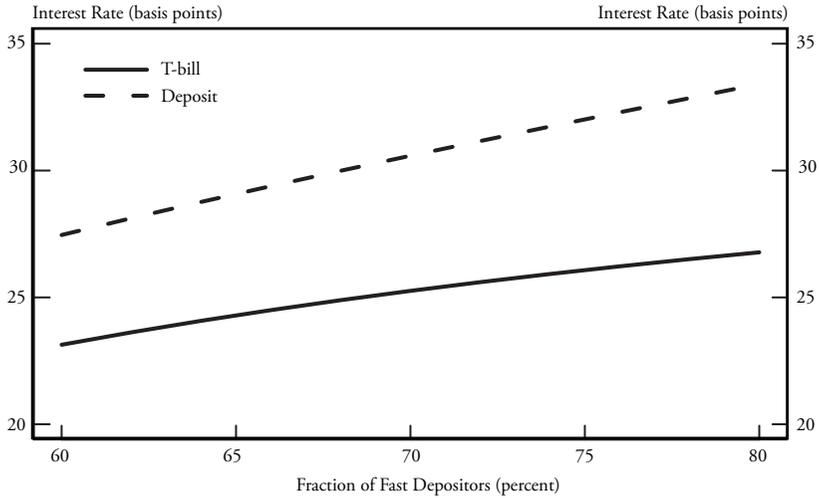
$$(1 - \mu)w + \mu W - V(g) = \frac{S}{1 + g} \quad (5)$$

The T-bill rate  $g$  solving this equation and the corresponding deposit rate distribution  $F_g$  constitute an equilibrium under technical conditions stated in Appendix B on the primitive parameters  $(\phi, c, \mu, k, K, W, w, S)$ . These technical conditions are satisfied in all of our numerical examples.

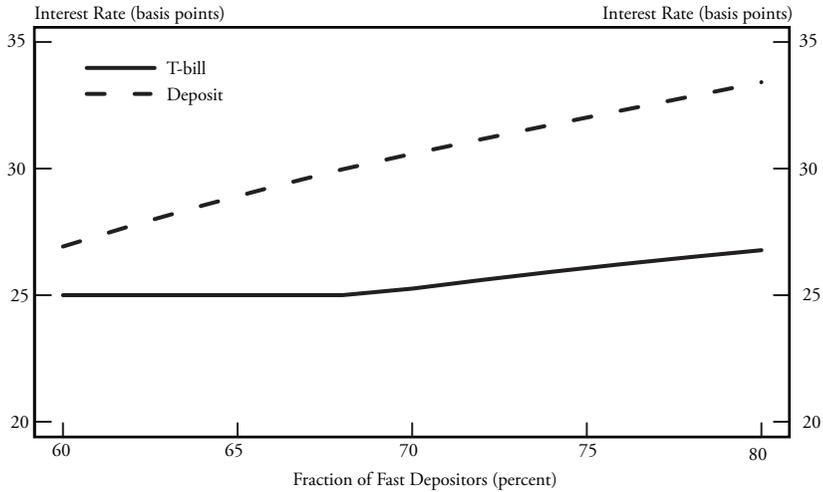
Taking a base-case IOER of 50 basis points, Chart 5 shows the modeled effect of increasing the fraction of fast investors, thus improving competition, on the pass-through of IOER to the T-bill rate and to the volume-weighted mean deposit rate across all investors.<sup>13</sup>

Chart 6, from Drechsler, Savov and Schnabl (2016), shows empirical counterparts of the rate spreads  $\phi - r$  and  $\phi - g$  over a sample from 1985 to 2016. Drechsler, Savov and Schnabl (2016) use the average effective federal funds rate over a given month as the empirical analogue of  $\phi$ . The deposit rate  $r$  is measured as the ratio of deposit interest expense for the banking system divided by total deposits, from the Call Reports. The T-bill rate  $g$  is measured as the average three-month T-bill rate for the given month. We see that both spreads are different from zero, as in our model. We also note that the spreads are positively correlated, suggesting that the factors driving imperfect pass-through in the deposit market are related to those causing imperfect pass-through in the T-bill market. In our model, this correlation arises because imperfect competition in the deposit market leads to low deposit rates, driving some investors into the T-bill market, pushing down T-bill yields. Chart 6 also reveals a correlation between these spreads and the level of rates. We later return to this relationship between the level of rates and rate dispersion.

**Chart 5**  
**A. Without RRP**

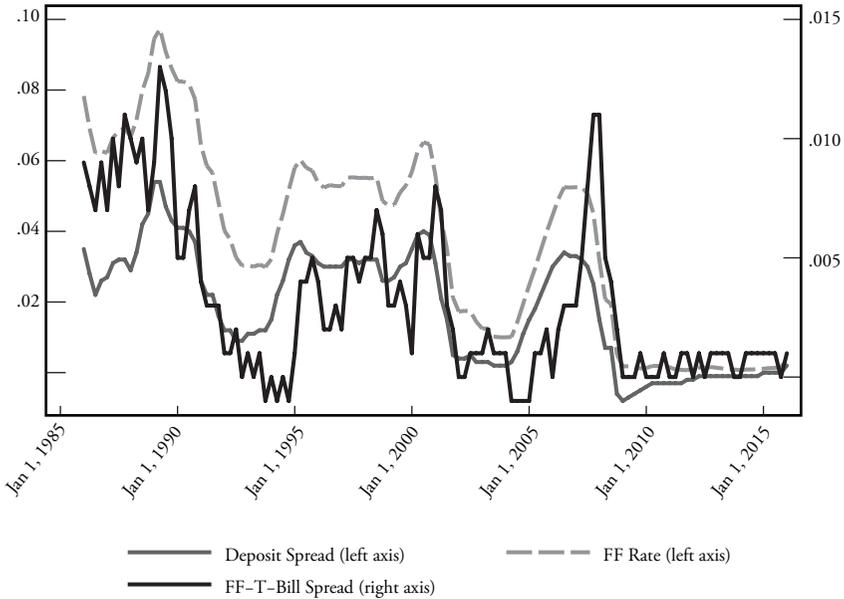


**B. With RRP**



Notes: The modeled effect of increasing the fraction of fast investors, thus improving competition, on the pass-through of IOER, at 50 basis points, to the T-bill rate and to the mean deposit rate, across all cash investors. These numerical examples are illustrative, and not quantitative predictions. This chart was drawn with the parameters  $\phi = 50 - 6.5 = 43.5$  bps,  $c = 4$  bps,  $N = 5$ ,  $K = 8$  bps,  $k = 4$  bps,  $w = 0.5$ ,  $W = 1.2$ ,  $S = 0.25$ , and  $\mu = 0.7$ .

Chart 6



Notes: The spread between the effective federal funds rate and both the average rate paid by banks on deposits and the three-month T-bill rate are graphed from 1985 to 2016. The federal funds effective rate is plotted on the left axis. The chart is from Drechsler, Savov and Schnabl (2016).

### *V.ii. The Pass-Through Impact of the RRP Facility*

Now we introduce the Fed's reverse repurchase facility (RRP), restricted to money market funds (MMFs), and with no cap on supply. MMFs can invest the funds they raise either in T-bills at the rate  $g$  or in RRP at some rate  $\rho_0 < \phi$  set by the central bank. The MMFs optimally choose to invest all funds in whichever of these two instruments offers the higher rate. When  $g = \rho_0$ , which can happen non-trivially in equilibrium, the amount invested in RRP is determined by the supply of T-bills and market clearing. That is, RRP absorbs the residual demand. The RRP rate  $\rho_0$  is thus a floor on the T-bill and MMF rates, but is not a floor on bank deposit rates.

For notational convenience, we let  $g_0$  denote the solution to the equation

$$\frac{S}{1+g_0} = (1-\mu)w + \mu W - V(g_0) \quad (6)$$

where  $V(\cdot)$  is given by (Equation 4). If  $g_0 \geq \rho_0$ , then the equilibrium T-bill rate  $g$  is given by  $g_0$ . If, however,  $g_0 < \rho_0$ , then the T-bill rate  $g$  is

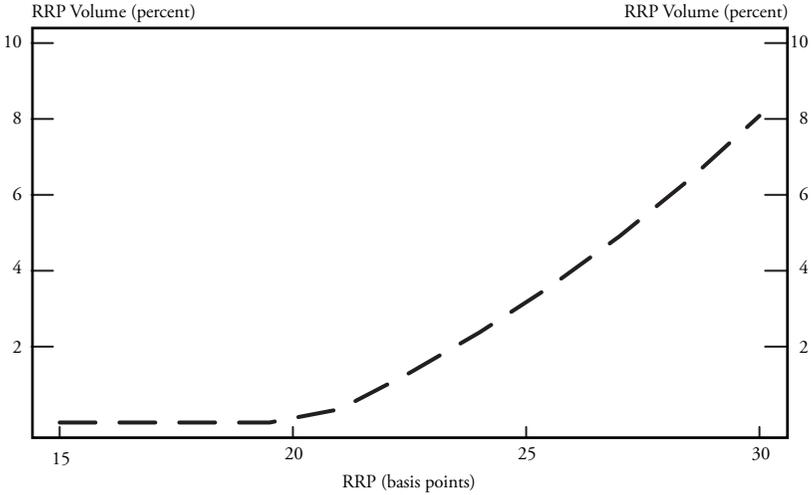
identical to the RRP rate  $\rho_\phi$  and the total demand for bank deposits is  $V(\rho_\phi)$ . The equilibrium deposit rate distribution  $F_g$  is as modeled in the base-case.

In practice, T-bill rates have often fallen below the RRP rate, indicating that investors do not treat the RRP and a T-bill as perfect substitutes. This is likely because T-bills offer additional convenience benefits relative to RRP. For example, T-bill transactions can be made at any time, whereas the RRP facility follows a prescribed schedule for cash investments and redemptions. T-bills can also be held by a wider set of money-market participants than those permitted to invest in RRP, an additional fungibility benefit of T-bills. Our model does not capture these additional causes of rate dispersion within money markets.

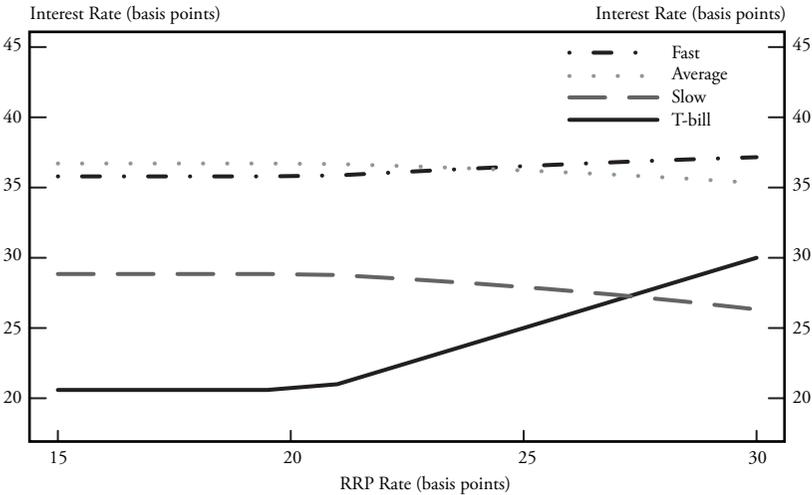
Chart 7 presents the effect in our model of increasing the RRP rate, holding IOER fixed at 50 basis points. Panel A graphs the take-up at the RRP, which as expected rises as the RRP rate crosses 20 basis points, which is the level of the T-bill rate with no RRP. Panel B plots the T-bill rate, as well as the average rates received by fast and slow investors on their investments. The rate shown for fast investors is the blended portfolio rate on T-bills, money funds and bank deposits, while for slow depositors this rate corresponds to their average bank deposit rate. The chart shows that increasing the RRP rate leads to an increase in the T-bill rate once the RRP rate exceeds 20 basis points. The blended rate received by fast depositors also rises over this range. This is the benefit of the RRP in increasing pass-through.

As shown, this increase in average pass-through to all money markets is achieved with a moderate reduction in pass-through to the average rate paid on bank deposits. As increases in the RRP rate cause some fast depositors to exit the deposit market and move into money funds and T-bills, the remaining clientele of bank depositors is more selected toward slow investors. The deposit market therefore becomes less competitive, and banks optimally respond by reducing their deposit rates. This RRP effect on deposit rates highlights a potential “footprint” concern associated with the RRP facility.

Chart 7



A. Holding IOER and other parameters fixed, the impact of increasing the RRP rate on the amount of investment in RRP, as a fraction of total money-market investment by all investors, in bank deposits, T-bills and RRP, whether directly or indirectly through money funds.



B. Impact of increasing the RRP rate on the equilibrium T-bill rate, the mean deposit rates of slow investors (“slow”), the mean rate on all bank deposits (“average”) and the mean blended rate (for deposits, T-Bills and money funds) achieved by fast investors (“fast”).

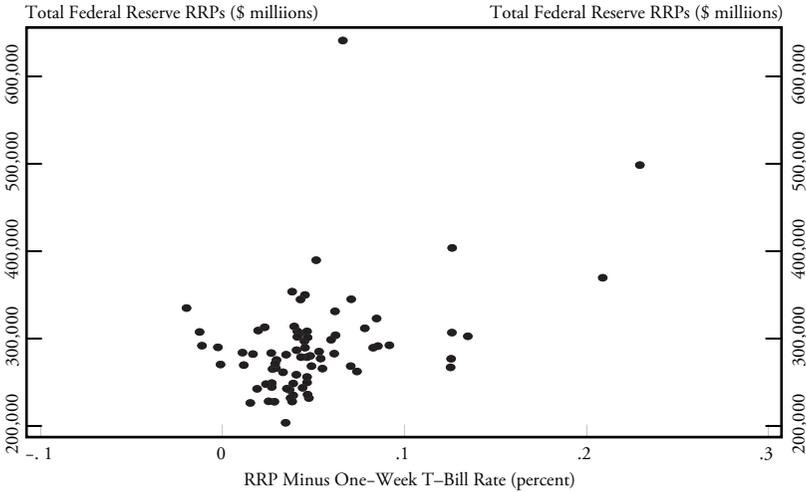
Notes: The modeled effect of increasing the RRP rate, when IOER is held at 50 basis points, on RRP take-up, shown in panel A, and on the T-bill rate, the average rate achieved by slow investors on bank deposits, and the average blended rate achieved by fast investors on T-bills, money funds and bank deposits, shown in panel B. These numerical examples are illustrative, and not quantitative predictions.

Chart 8 presents data on Fed RRP. We plot the quantity of Federal Reserve reverse repurchase agreements, in millions of dollars, against the spread between the RRP rate and the one-week T-bill rate. The data, from Jan. 1, 2015 to June 30, 2016, show a positive relationship between this spread and the volume of RRP, consistent with our theoretical analysis.

Chart 8 includes the quantity of repurchase agreements with the private sector and foreign central banks. Foreign central banks invest cash in a Fed facility known as the “foreign repo pool.” These investments have become more significant over the last year, growing from about \$100 billion at the start of 2015 to nearly \$260 billion in June 2016. Because foreign central banks can substitute between T-bills and reverse repos with the Fed, the existence of the foreign repo pool could improve pass-through into the T-bill market, given that short-term T-bill rates are below repo rates, including those offered in the TPR market.<sup>14</sup>

The Federal Open Market Committee (FOMC) has stated in its “Policy Normalization Principles and Plans” that it will gradually reduce reserve balances and phase out the RRP program as its monetary policy normalizes.<sup>15</sup> To the extent that the RRP facility aids average pass-through, as our analysis suggests, phasing out the RRP program would reduce pass-through. In order to operate at large scale, the RRP facility also requires a sizable Fed balance sheet and the payment of IOER. If the Fed were to revert to a setting in which federal funds rates are controlled by binding reserve requirements, the systemwide quantity of reserves would be so small that shocks to the usage of RRP would result in significant volatility in the federal funds market. The FOMC’s “Policy Normalization Principles and Plans” does not specify the size of a normalized balance sheet or whether the Fed would continue its IOER policy. Chair Janet Yellen, in a speech at this conference Aug. 26, 2016, stated that “IOER will still be important as a contingency tool,” indicating that a sizable balance sheet and the payment of IOER will be a deviation from the normalized policy. Our analysis suggests that pass-through benefits from the RRP require that normalized policy involves a large balance sheet for the Federal Reserve and the payment of IOER.

Chart 8



Notes: A scatter plot of volumes of Federal Reserve reverse repurchase agreements, in millions of dollars, and the spread, in percent, between RRP rate and the one-week T-bill rate, from Jan. 1, 2015 to June 30, 2016, based on weekly data.

Sources: Federal Reserve and CRSP.

### *V.iii. With Tri-Party Treasury Repos*

We can reinterpret our basic model so as to derive implications for equilibrium rates on repos backed by government securities. Suppose that MMFs can invest both in T-bills at the rate  $g$  and in government-security repos at the rate,  $r_p$ , which we may conceptualize as the TPR rate. As before, fast investors can invest in either T-bills directly or in MMFs. Because these two investments are indistinguishable in our model from the standpoint of investors, it follows that

$$r_p = g. \quad (7)$$

The introduction of repos alters the market-clearing condition for T-bills. We let  $S_{RP}(r_p)$  denote the quantity of general-collateral Treasuries (after haircuts) that would be supplied to the repo market at the repo rate  $r_p$ . We naturally take  $S_{RP}(r_p)$  to be decreasing in  $r_p$ .

Using Equation 7, we can extend Equation 5 to the market-clearing condition for total investment in T-bills and repo, as

$$(1 - \mu)w + \mu W - V(g) = \frac{S + S_{RP}(g)}{1 + g} \quad (8)$$

This equation determines  $r_p = g$  and  $S_{RP}(r_p)$ .

Here, the RRP rate  $\rho_0$  is a floor on both  $r_p$  and  $g$ . Without the RRP facility, when market conditions cause a drop in both  $r_p$  and  $g$ , the quantity of TPR expands. With the RRP facility, however, when market conditions cause  $r_p$  and  $g$  to fall, the quantity of TPRs can reach at most  $S_{RP}(\rho_0)$ . That is, the RRP facility implicitly caps the quantity of TPR. We return to this discussion in Section V.v when discussing how the RRP facility may squeeze the repo market in a flight-to-quality episode.

#### ***V.iv. Depositor Attention Deficit***

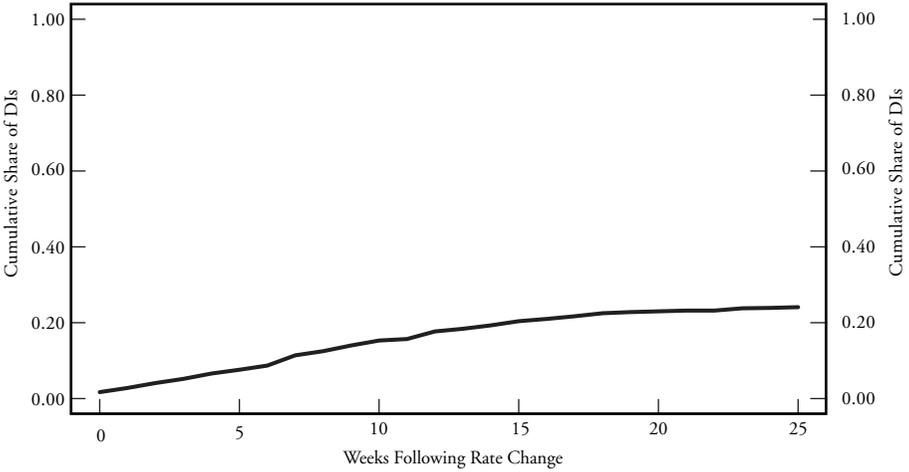
Section II reviews some of the abundant empirical evidence that retail depositors have low awareness of changes in wholesale interest rates, and that banks exploit them accordingly.<sup>16</sup> For example, Chart 9, from Driscoll and Judson (2013), illustrates that when wholesale rates go down, banks immediately lower their deposit rates, as shown in Panel B. When wholesale rates go up, as in Panel A, banks are remarkably slow to increase their deposit rates. They fail to compete with each other aggressively for the usual reason that slow investors have search and monitoring costs that limit comparison shopping, and now also because slow investors are unlikely to be aware that other banks have shifted their rates upward a bit in order to attract funds from more alert fast investors.

We now extend our model to capture depositor attention costs. Prior related work by Yankov (2014) focuses on the asymmetric deposit-rate responses of banks to changes in their cost of funds, but not on the implications for pass-through to other money markets.

At a particular choice of IOER and corresponding marginal benefit  $\phi_0$  for gathering deposits, let  $F_0$  denote the corresponding equilibrium deposit offer distribution, as calculated in Section V.iii. We consider a scenario in which an increase in IOER causes banks to have a higher marginal benefit  $\phi_1$  for gathering deposits, and thus a new deposit-rate offer distribution  $F_1$ . Fast investors are fully aware of all current market rates. Slow investors, however, are not aware of this change until after making their deposit decisions. Once visiting a bank and seeing a deposit rate  $r$ , they decide whether to accept the rate based on the assumption that alternative banks are offering rates drawn from the old rate distribution  $F_0$ . We can extend to allow slow

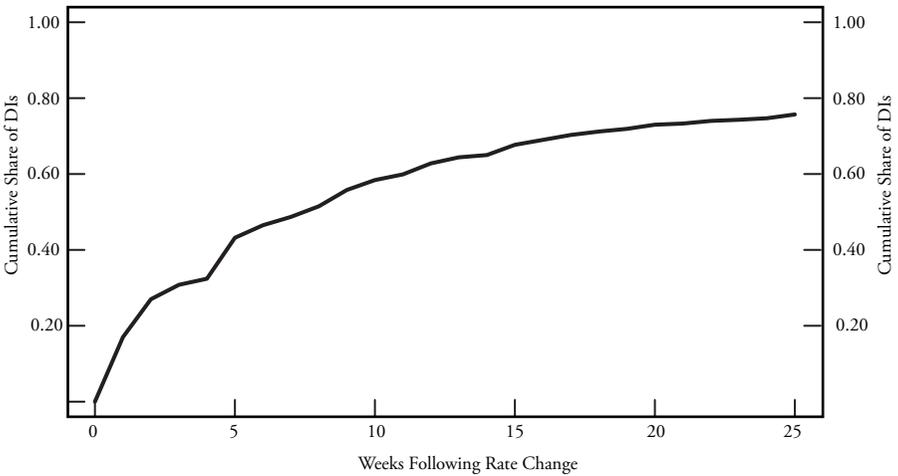
**Chart 9**

**A. Increase in Target Fed Funds Rate, June 30, 1999\***



\*The fraction of depository institutions responding with higher MMDA rates after the Fed raised its target rate on June 30, 1999.

**B. Decrease in Target Fed Funds Rate, March 30, 2001\*\***



\*\*The fraction of depository institutions (CDI) responding with lower MMDA rates after the Fed lowered its target rate on March 20, 2001.

Notes: Examples of the asymmetric response of depository institutions to changes in Fed target rates. In each panel, the horizontal axis shows the number of weeks after the announcement of a change in target rate. The vertical axis corresponds to the fraction of depository institutions that, by a given week after the announcement, had responded with a change in the rate offered on their money market deposit accounts (MMDAs). The figures are from Driscoll and Judson (2013).

investors to consider the possibility that alternative rates might be drawn from  $F_I$ .<sup>17</sup>

A bank's indifference condition for a rate  $r$  in the support of its offer distribution  $F_I$  is in this case

$$\left[ \mu F_I(r)^{N-1} D(r; g, g) + \frac{1-\mu}{N} w \right] (\phi_I - r) = \frac{1-\mu}{N} w (\phi_I - \underline{r}_0), \quad (9)$$

where  $\underline{r}_0 = r_{F_0} - c$  is the old search-indifference rate for slow investors. This equation determines a new offered rate distribution  $F_I$  that is above (in the sense of first order dominance) the old offered rate distribution  $F_0$ , but below the offered rate distribution that would apply if slow investors were aware that the value of the outside option to search is actually  $r_{F_I} - c$ , above their assumed search value of  $r_{F_0} - c$ .

Table 2 presents the results of our analysis. For a given increase in IOER from the base case of 50 basis points to 75 basis points, 100 basis points, or 125 basis points, the table presents the pass-through to the T-bill rate as well as the average rates received by fast and slow depositors. For comparison, we present pass-through for both cases: attention deficit and no attention deficit. The table shows that attention deficit reduces pass-through to all rates. As anticipated, the slow-investor rates are most affected. We emphasize that the T-bill rate is also affected by the attention costs of slow investors, even though the T-bill rate is set by investors who are competitive, face no attention deficit, and trade T-bills in a Walrasian (fully competitive) market. The stickiness in deposit rates induced by attention costs leads some fast investors to peel away from deposits and increase their demand for MMFs and T-bills, causing the pass-through of IOER changes to the T-bill rate to be less than one for one. This helps explain the correlations between the level of the FFER and the spreads between FFER and deposit rates and FFER and T-bill rates documented by Drechsler, Savov and Schnabl (2016) (see Chart 6).

This substitution into T-bills induced by imperfect competition and depositor inattention helps explain the sluggish response of the T-bill rate to the increase in IOER on Dec. 17, 2015, pictured in Chart 3. A sluggish and asymmetric response of T-bill rates to fed

**Table 2**

		Base + 25 bps	Base + 50bps	Base + 75bps
No Attention Deficit	T-bill ( <i>g</i> )	24.6	49.9	74.5
Attention Deficit	T-bill ( <i>g</i> )	20.0	39.4	59.0
No Attention Deficit	Fast	24.9	50.0	75.0
Attention Deficit	Fast	21.4	42.2	62.6
No Attention Deficit	Slow	25.1	50.0	75.1
Attention Deficit	Slow	10.3	19.2	26.9

Notes: The impacts of upward shifts in IOER on various money market rates, for a model in which slow investors have attention costs, in addition to costs for search and monitoring. For a column marked "Base + *s*," IOER is shifted from 50 basis points to *s* + 50 basis points. The shift in the rate marked "fast" is the increase, in basis points, in the volume-weighted blended rate paid on the money-market portfolio of fast investors. The shift in the rate marked "slow" is the increase, in basis points, in the average deposit rate paid to slow investors. These numerical examples are illustrative, and not quantitative predictions.

funds rates was also found in pre-2000 data analyzed by Sarno and Thornton (2003), although they did not offer an explanation. Our model provides an explanation. We return to a discussion of this issue in Section V.vi.

We can also consider how the RRP will affect equilibrium rates under the effect of attention costs. As we have shown, the RRP improves pass-through to the T-bill rate, but can worsen pass-through to the deposit rates paid to slow investors. Attention deficit exacerbates both effects. With attention deficit and RRP, more fast money moves into the RRP and T-bill markets, and the beneficial effect of RRP in improving pass-through to these rates improves. On the other hand, the RRP facility causes banks to be even less competitive because the depositor selection bias induced by greater migration of fast investors to RRP causes the equilibrium pool of depositors to include a relatively higher fraction of slow investors. In fact, after an increase in IOER, the presence of RRP actually *worsens* the pass-through of increases in IOER to average deposit rates.

### ***V.v. RRP and Liquidity Withdrawal from Private Markets***

We have discussed three principal sources of pass-through inefficiency: imperfect competition, segmentation and regulation. In this setting, we have shown how the RRP facility improves pass-through to wholesale market rates. Our analysis, however, also suggests a negative aspect of the RRP facility. The associated expansion of the Fed's footprint in money markets can lessen market discipline, lower the

effectiveness of price discovery and reduce pass-through into some deposit rates.

This section discusses another concern, namely that the RRP may exacerbate instability during a flight to quality. The minutes of the FOMC meeting of June 17-18, 2014, highlight the concerns of some members that, in times of financial stress, investors would shift cash investments to the RRP facility, thereby disrupting funding to the private sector and exacerbating the financial stress.<sup>18</sup>

A shift of private investments into the RRP facility, by definition, decreases total bank reserves. This shift does not alter total Fed liabilities, but rather changes the composition of Fed liabilities. In a frictionless world, one in which all of the pass-through channels depicted in Figure 1 operate efficiently, this compositional change would have no effect on money market equilibrium rates. In practice, however, this shift of cash into the RRP would raise some concerns, which we now address.

The effect of an increased preference for RRP relative to other investments is similar to the comparative-static effect of reducing the coefficient in investors' utility functions (currently set to 1) for deposits (to a number below 1), and leaving the utility coefficients for risk-free payoffs equal to 1, reflecting an aversion to credit loss on bank deposits. As a result, T-Bills and RRP would be relatively more attractive. More fast-investor money would flow (through money funds) into the RRP facility and out of bank deposits. This would lead to a relative reduction in the rates offered to slow cash investors, after controlling for the credit-spread effect, thus increasing dispersion (after adjusting for credit spreads).

A second effect would arise through a reduction in the quantity of bank reserves. If bank-held reserves are scarce, a flight to RRP would reduce the quantity  $R$  of reserves and raise wholesale rates. (We analyze this case formally in Section VI.iii.) But currently there are excess reserves in the banking system. So, the latter effect would not currently be present. A sudden flight to RRP could affect weaker banks, so that even if reserves as a whole are plentiful, weaker banks are left scrambling for liquidity. These banks would likely turn to the

Fed's discount window, cushioning the withdrawal shock. All in all, the impact on the banking-sector stability is not likely to be crucial.

A third effect is the corresponding potential flight from funding securities dealers, who could be squeezed for liquidity by a sudden drop in repo funding and increase in the GCF repo rate. Shortly after Brexit, for instance, the GCF repo rate briefly rose from about 45 basis points to nearly 90 basis points. Sections 23A and 23B of the Federal Reserve Act severely limit the ability of a primary dealer to obtain liquidity from its affiliated bank. Although Dodd-Frank now prohibits the Fed from making emergency loans to individual dealers, it could set up a programmatic facility along the lines of the primary dealer credit facility (PDCF). Alternatively, or in addition, the Fed could engage in open-market operations with primary dealers, offering repo funding against eligible collateral, which includes Treasuries. Without extra liquidity provision along these lines, a flight to the RRP facility could have a serious impact on the stability of some securities dealers.

To this point, our discussion assumes an uncapped RRP, or a cap that is so large that it does not bind. Suppose, instead, that there is a binding aggregate quantity cap, denoted  $CAP$ , on RRP usage, and that RRP allocation is determined by an auction. The equilibrium in our model would be the same as for the case without an RRP, but with the supply of T-bills increased from  $S$  to  $S + CAP$ . We let  $g^{CAP}$  denote the corresponding market clearing rate for T-bills, which in our model is also the auction clearing rate for the RRP facility. Clearly  $g^{CAP}$  is less than  $\rho_0$ , the RRP rate when the CAP does not bind. The CAP makes the RRP facility less attractive during a flight to quality by reducing the return on safe government assets, and thus dampens the flight-to-quality effects that we have described.

#### *V.vi. Raising Rates*

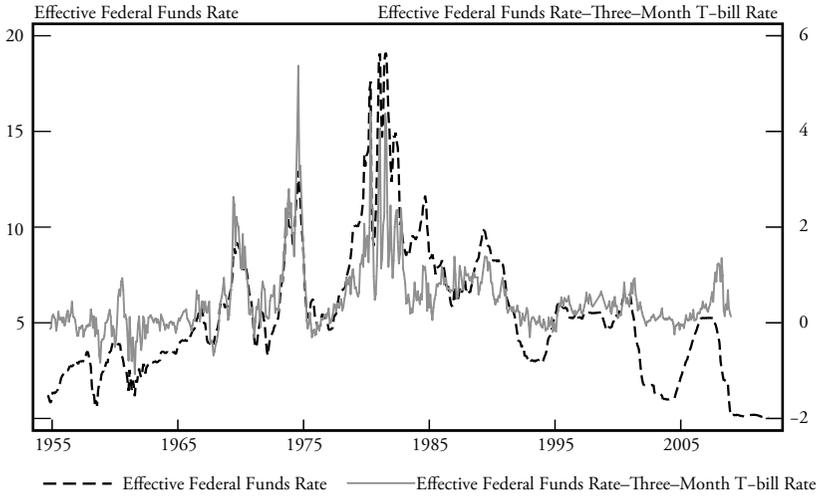
Money-market dispersion and money-market spreads are positively correlated with the Fed's target rate, as documented by a number of empirical studies. We have modeled how dispersion is increased by investors with attention deficit. When the IOER rises, banks increase their offered deposit rates by less than one for one, exploiting their

local-monopoly power over “slow” depositors. This induces fast investors to substitute bank deposits with alternative assets such as money market funds or T-bills, reducing aggregate levels of bank deposits. As a consequence, T-bill rates also rise by less than one for one with IOER, and there is an increased take-up at the RRP facility.

We begin this section by reviewing some of the evidence for these modeled relationships. Figures 1 and 6 of Drechsler, Savov and Schnabl (2016) imply strong correlation between the level of the FFER and two different aspects of rate dispersion: 1) the spread between FFER and deposit rate, and 2) the spread between FFER and the T-bill rate. Chart 6 reproduces the information in Figures 1 and 6 of their paper. Panel D of Figure 1 of their paper also shows that increases in FFER are correlated with outflows from core bank deposits. Figure 1 of Nagel (2016), replicated in Chart 10, shows a tight relationship between the level of FFER and the FFER minus T-bill rate spread in a sample from 1954 to 2008.

Chart 11 is based on our work. Panels A and B present scatter plots of changes in the FFER-to-T-bill spread against changes in FFER, based on monthly data from 1954 to 2008. Each observation corresponds to the one-month change in the monthly average of the underlying rates or spreads. Panels C and D present analogous scatter plots of the spread between three-month secondary-market CD rates and three-month T-bill rates, using data from 1964 to 2008. Panels A and C are restricted to observations for which the T-bill supply was in its lowest sample quartile, while Panels B and D are for observations when the T-bill supply was in its highest sample quartile. Each figure shows the ordinary least squares-fitted regression line.

If pass-through was on average one for one, these fitted regression lines would be horizontal. The slopes of these lines are measures of imperfect pass-through. We see from all of these panels that the slope is positive, consistent with the work of Nagel (2016) and Drechsler, Savov and Schnabl (2016). But we also see that the slope is lower when there is a larger supply of T-bills. Krishnamurthy and Vissing-Jorgensen (2012) document a negative relationship between Treasury supply and spreads over a sample from 1919 to 2008. Our results here are similar in spirit, but based on changes in spreads and the FFER.

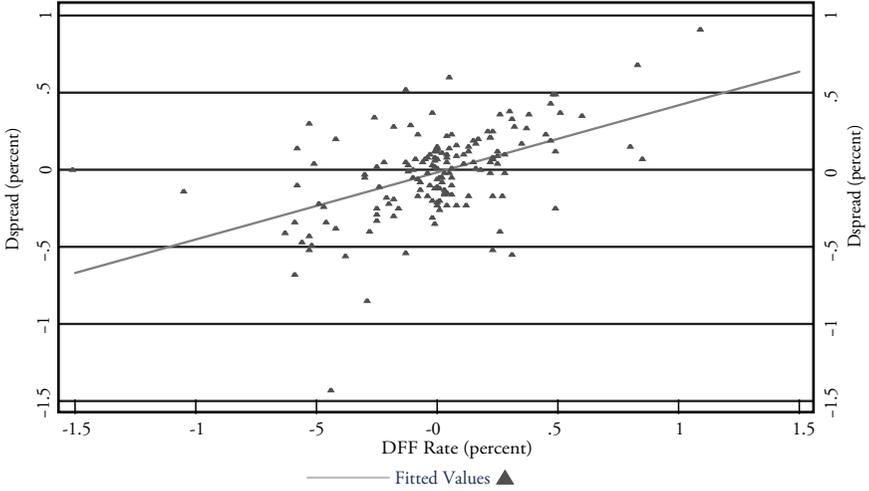
**Chart 10**

Notes: We plot the spread between the federal funds effective rate and the three-month T-bill, monthly from 1954 to 2008. We also plot the level federal funds effective rate. The chart closely resembles Figure 1 from Nagel (2016). Data source: Federal Reserve.

### Chart 11

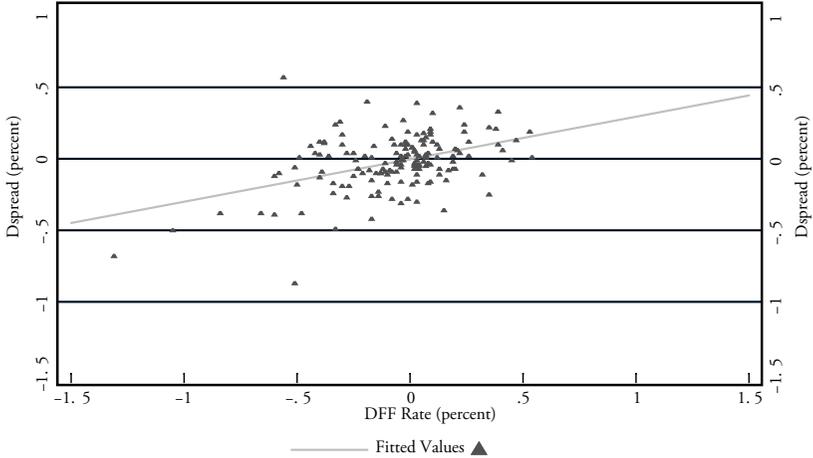
#### A. Fed Funds-T-bill; Low Supply

D(FF-3mTbill) Spread v.s. DFFRate, 1st Quartile Tbill Supply

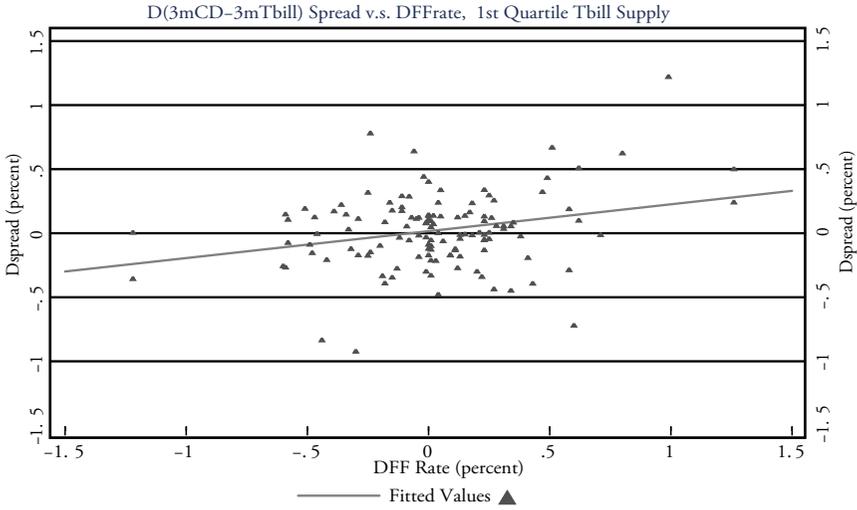


#### B. Fed Funds-T-bill; High Supply

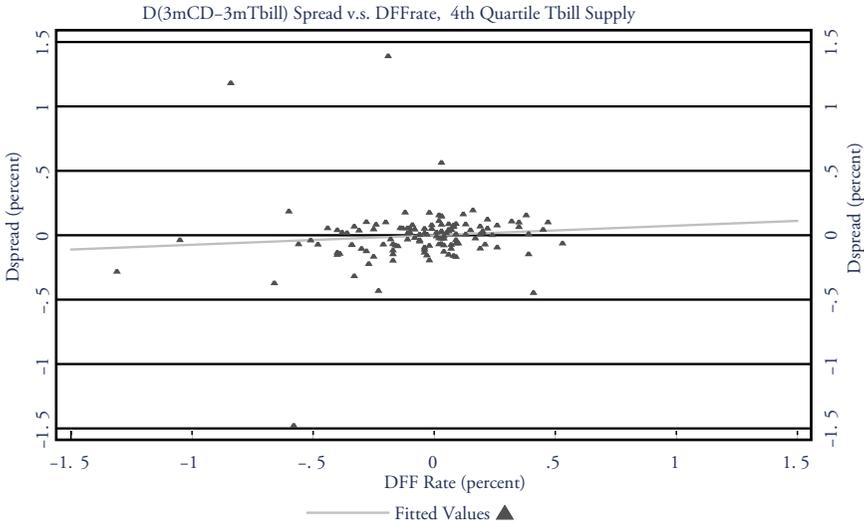
D(FF-3mTbill) Spread v.s. DFFRate, 4th Quartile Tbill Supply



### C. CD-T-bill; Low Supply



### D. CD-T-bill; High Supply



Notes: Each panel is a scatter plot of the monthly change in a spread versus the monthly change in the federal funds effective rate rate, for different spreads and different outstanding amounts of T-bills. The black line in each figure is the OLS-fitted regression line. Panels A and B are for the federal funds effective rate minus three-month T-bill spread. Panels C and D are for the three-month CD minus three-month T-bill spread. The left figures correspond to low T-bill supply, measured as the first quartile of T-bill supply; while the right panel corresponds to high T-bill supply, measured as the fourth quartile of T-bill spread. All rates and spreads are based on averages of the daily rates for a given month. The sample for panels A and B is from 1954 to 2008, while for panels C and D it is 1964 to 2008. Data sources: Federal Reserve and U.S. Treasury.

**Table 3**

		T-Bill Supply		
		0.15	0.25	0.35
Base IOER + 25 bps	T-Bills	20.27	20.79	21.47
	Fast Investor	20.74	21.15	21.75
	Slow Investor	9.7	8.87	8.43
Base IOER + 50 bps	T-Bills	40.18	41.72	42.91
	Fast Investor	40.56	40.91	41.23
	Slow Investor	18.2	16.47	15.6

Notes: These numerical examples are illustrative, and not quantitative predictions. The pass-through of policy rate increases to money-market rates, under various supplies of T-bills. The tabulated quantities are the impacts of the indicated increases in IOER, from the base case of 50 basis points, on equilibrium T-bill rates, average money-market portfolio rates paid to fast investors, and average deposit rates paid to slow investors. The T-bill supply is shown as a fraction of the total market value of wholesale money market instruments (T-bills, RRP, and fast-investor bank deposits).

This effect of T-bill supply on pass-through is present in our imperfect-competition model. Table 3 shows how pass-through in our model changes with increases of 25 basis points and 50 basis points in the IOER rate from its base case of 50 basis points, for three levels of T-bill supply. In our model, when the shadow value  $\phi$  to banks of collecting deposits rises with increases in IOER, some fast depositors shift their demand toward T-bills. If the T-bill supply is small, however, T-bill rates do not rise by as much as  $\phi$ . When the T-bill supply is large, there is an improved substitution effect for the pass-through of IOER into T-bill rates. The table illustrates this effect. With a greater supply of T-bills, there is improved pass-through of IOER increases to T-bill rates and to the average portfolio money market rates paid to fast investors. Pass-through to bank deposit rates decrease, because of the selection effect we have described earlier.

The T-bill evidence can inform us about how the RRP facility may affect equilibrium when rates rise. Adding the RRP facility increases the quantity of “quasi-T-bills,” once rates fall to the RRP rate. We say “quasi” because RRP investments are similar to but not the same as T-bills. An RRP with the Fed is an overnight government-quality investment, rather than a term investment such as a four-week T-bill. An RRP investment, moreover, can be held only through a subset of the financial sector, such as the money market fund sector, whereas

T-bills can be held by any investor. Finally, while T-bills have intraday liquidity, an RRP investment is an overnight instrument. These differences notwithstanding, when T-bill rates fall, investors have an incentive to move their funds into the RRP facility, increasing the effective supply of government paper, and thus increasing average pass-through.

Garratt, Martin, McAndrews and Nosal (2015) present a proposal for “Segregated Balance Accounts” (SBAs) that, in the context of our analysis, offer benefits and costs similar to those associated with augmenting the supply of T-bills. Under the SBA proposal, depositors would place funds with a bank in an account that is segregated from the rest of the bank’s balance sheet and from its operational control, so that the funds are not subject to the bank’s credit risk and cannot be accessed by the banks, for example, to fund a loan. The bank in turn holds these funds at the Federal Reserve in an SBA, earning interest at the IOER rate. The SBA would give depositors effective access to Fed-quality assets, thus bypassing the institutional segmentation illustrated in Figure 1. The rates offered by banks to depositors on SBA-backed accounts, however, would depend on the degree of competition among banks for these deposits. In our analysis, as with the RRP facility, the SBA would improve pass-through to the T-bill rate. As with RRP, SBAs would cause some footprint concerns. Unlike RRP, however, SBA-backed accounts are not limited in quantity and would be available to any depositor, even retail depositors.

## **VI. Pass-Through Impacts of Balance Sheet Regulations**

This section examines the pass-through implications of the SLR rule and the LCR rule. We do not analyze the pass-through impacts of the net stable funding ratio (NSFR) rule, which may place an additional shadow price on balance sheet space for short-term bank or bank-dealer liabilities.<sup>19</sup> Of the three new balance-sheet regulations, SLR, LCR and NSFR, the SLR currently has the largest adverse impact on pass-through. We analyze, however, the potential for LCR to significantly impinge on the supply of HQLA when rates normalize at higher levels, unless there is a compensating increase in the Treasury’s or Fed’s supply of short-term HQLA.

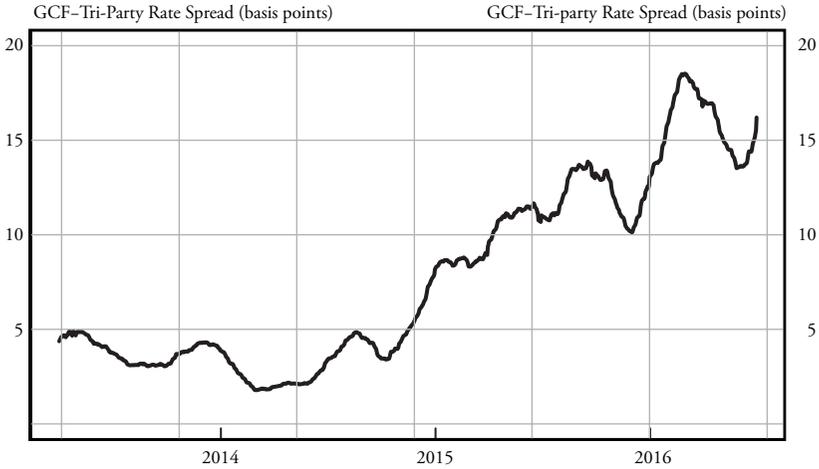
***Vi.i. Pass-Through Inefficiency Under the Leverage Ratio Rule***

Even within the U.S. Treasury repo market, significant rate dispersion and allocative inefficiencies are likely to have been caused by the SLR rule. The U.S. version of the leverage-ratio rule for the largest bank holding companies now requires these firms to have a minimum ratio of capital to total assets of 5 percent, regardless of the risk composition of their assets.<sup>20</sup> European banks are currently subject to a 3 percent SLR. Per unit of gross assets, intermediation of repos backed by government securities has extremely low risk and low profit margins per unit of assets. This suggests that repo intermediation incentives are likely to be impaired by debt overhang, in the sense of Myers (1977), whenever SLR is viewed by major dealers as a potentially binding constraint. We will present evidence that SLR is indeed viewed as a binding constraint by marginal dealer participants in the U.S. repo market. To reserve balance sheet space for the intermediation of repos, SLR forces a bank-affiliated dealer to increase its capital by enough that unsecured creditors are made safer, improving the market values of the creditors' claims through an effective wealth transfer from shareholders. This wealth transfer effect causes dealers to increase their bid-ask spreads enough that the wealth-transfer effect on shareholders is offset by repo intermediation profits. As bid-ask spreads increase, trade volumes decline.

Repo market intermediation is crucial to pass-through in the U.S. monetary setting. For example, according to Ruane (2015), repos constitute 41 percent to 48 percent of total wholesale funding markets. Repos are also one of the main operational tools for the Fed's monetary policy setting, through both open market operation and the Fed's RRP facility. Further, the pass-through of Fed policy rates into longer-term bond yields relies on repo-rate pass-through, given that bond-market liquidity providers, including dealers and hedge funds, finance their bond positions in the repo market.

Based on data presented by Martin (2016), GCF repo volumes have declined by about 30 percent since 2012. The amount of cash financing obtained from bank-affiliated dealers by nonbank-affiliated dealers in this market has declined by about 80 percent from 2013

Chart 12



Notes: Rolling 90-day average of the spread in basis points between the overnight GCF repo rate and the overnight tri-party repo rate. The rolling-average window is designed to capture one quarter-end balance-sheet effect in each window. Data sources: Bloomberg and Bank of New York Mellon.

to the end of 2015. In the last two years, a proxy measure of the effective bid-ask spread for U.S. government securities repo intermediation has increased from under 4 basis points to about 16 basis points, as shown in Chart 12. This spread is the difference between the financing rates paid by nonbank-affiliated dealers in the GCF repo market, relative to the financing rates paid by bank-affiliated dealers (among others) in the TPR market. In the last quarter of 2015, the three-month Treasury-secured repo rates paid by nonbank dealers were higher even than the three-month unsecured borrowing rates paid by banks (LIBOR), a clear and significant market distortion.

For a simple model of the magnitude of the SLR impact on repo bid-ask spreads, consider a bank-affiliated securities dealer that is subject to consolidated capital requirements under the Basel global systemically important bank (G-SIB) standards.<sup>21</sup> For simplicity, suppose that the SLR is binding for this bank, so that it must have at least  $C$  in additional capital for each additional unit of measured assets, regardless of the asset risk. On a candidate repo trade, the bank would initially receive from its counterparty Treasuries with a market value of  $1 + H$  in exchange for 1 in cash, where  $H$  is the overcollateralization, or “haircut,” designed to protect the bank from counterparty failure. At maturity in one day, the bank returns the Treasuries to the counterparty

in exchange for  $1+r_p$ , where  $r_p$  is the repo rate, measured for notational simplicity on a per-day (rather than annualized basis). The repo rate  $r_p$  exceeds the bank's cost of funds by some rate spread  $G$ . In this case, the bank can obtain funding in the repo market by using the same Treasuries as collateral.

Repos are exempt from stays at counterparty failure, so the bank could suffer an unexpected loss on this trade only if, within a day, both of two unusual events happen: 1) the counterparty defaults and 2) the value of the Treasuries drops by more than the haircut  $H$ . In practice, this combined outcome is so unlikely that an event of this type has not been reported since the 1982 failure of Drysdale Government Securities, when repo counterparties had mistaken their haircut assignments.<sup>22</sup> So, in the absence of capital requirements, because this trade is nearly risk free trade, it has almost no effect on the market values of the bank's debt and equity, other than the intermediation gain of  $G$ , which we can assume for simplicity is paid to equity as a distribution. Because the SLR is binding, however, the bank must have approximately  $C$  in additional equity in order to conduct this trade. A simple and reasonable way for the bank to arrange this additional equity is to retire approximately  $C$  worth of unsecured debt, funded by an equity issuance of the same amount. In practice, the bank would not conduct an equity issuance for each repo trade. Instead, it would have a policy for how much repo it wishes to conduct on a normal ongoing basis, and adjust its capital structure so as to meet its capital requirements, with some buffer designed to conservatively avoid compliance problems.

In our simple example, the remaining legacy unsecured creditors benefit to the extent that the retired debt no longer claims a share of the recovery value of the bank's assets in the event that the bank defaults. Instead, that default-contingent recovery claim is absorbed by the remaining unsecured creditors. The market value of this additional default-contingent debt recovery claim, per unit of retired debt, is the difference between the market value of a default-free debt claim and the market value of an unsecured debt claim on the bank. This difference is therefore equal to the credit spread  $S$  on the bank's unsecured debt. Because  $C$  units of debt were retired, the net gain

in value to the legacy debt is therefore  $CS$ . Because the balance sheet of the bank is otherwise unaffected, the shareholders' net gain is the funding spread  $G$  on the repo trade less the wealth transfer of  $CS$  to legacy unsecured creditors. Thus, the incremental impact of the capital requirement on the bank's incentive to conduct the repo is equal to  $CS$ .

For illustration, consider an SLR of 5 percent and a typical annualized average unsecured credit spread for bank holding companies of 120 basis points, as inferred from the CDS market. A bank-affiliated dealer must therefore lower its bid and raise its offer for Treasury repo intermediation by  $CS = 6$  basis points each to compensate its shareholders for the debt-overhang effect of SLR, for a total impact on the bid-offer spread of 12 basis points. This impact is similar in magnitude to the empirical effect shown in Chart 12.

Section VIII discusses potential improvements in market infrastructure that would reduce the amount of dealer balance sheet space necessary to intermediate the repo market, thus mitigating pass-through inefficiencies associated with the SLR. Another option would be to change the application of the SLR to U.S. government securities repo intermediation. For example, the measured amount of assets represented by government securities repo intermediation could be modified so as recognize the effect of netting when it is achieved safely within the same asset class. (The SLR rule already permits some netting of repo positions with the same counterparty, but not across counterparties.) An alternative would be to increase conventional risk-weighted capital requirements to the point that SLR is not close to binding.

### ***VI.ii. Pass-Through Impacts of Quarter-End SLR Window-Dressing***

In addition to the average pass-through impacts of SLR that we have discussed, the SLR induces a pronounced increase in money market rate dispersion at the end of each calendar quarter. This section begins by describing and interpreting these patterns. Then, we discuss how these patterns inform us about the potential effects of increases in rates and changes in regulation.

**Table 4**

Variable	Mean, Excluding Quarter-End	Quarter-End Change	95% Confidence Interval
Fed Private-Sector RRP volume	\$94.2 bn	\$206.1 bn	[170.6, 241.5]
One-Week T-Bill Rate–IOER	–26.3 bps	–6.7 bps	[–10.9, –2.5]
O/NTPR TSYrepo–IOER	–19.4 bps	0.0 bps	[–1.5, 2.2]
O/N GCF TSY repo–IOER	–6.4 bps	26.4 bps	[21.0, 31.7]
O/N Non-Fin CP–IOER	–17.0 bps	–5.0 bps	[–7.0, –3.1]

Note: End-of-quarter effects on selected money-market rates, for the period Jan. 1, 2015 to June 30, 2016.

Table 4 provides statistics bearing on the end-of-quarter effect on money-market rates. The sample is from Jan. 1, 2015 to June 30, 2016. We report the mean value of a variable, excluding the end of quarter, as well as the change at the end of quarter, and the 95 percent confidence interval around this change.

The table shows that take-up at the Fed's RRP facility increases by an average of \$206.1 billion at the ends of quarters. We also see that the one-week T-bill rate and the overnight nonfinancial commercial paper rate fall by between 5 basis points and 7 basis points. When interpreting the fall in the one-week T-bill rate, one should keep in mind that the T-bill rate reverses and rises back to the average value the day after quarter-end. The movements in the one-week T-bill rate imply that the overnight return on T-bills falls by 47 basis points. That is, had we measured a rate on overnight T-bills we would have seen a very large decline in their rates. The data also show that the GCF treasury repo rate, rises on quarter-ends by an average of 26 basis points, whereas the TPR is nearly unchanged. Finally, the table shows that all of these rates are on average below the IOER rate, with the T-bill rate and the TPR rate the lowest, and the GCF repo rate the highest. In mid-2016, the GCF repo rate has gone well above IOER on quarter-ends.

These effects are consistent with banks, especially banks with headquarters in foreign countries, and bank-affiliated dealers scaling back their balance sheets at the ends of calendar quarters. When dealers scale back their balance sheets, they do less matched-book repo intermediation. For example, they borrow less in the TPR market and lend less in the GCF repo market. The resulting contraction in

lending in the GCF repo market drives up the GCF repo rate. At the same time, because banks scale back borrowing at quarter-ends, cash investors that normally invest in bank deposits seek alternative cash investments. This explains the fall in the one-week T-bill rate and the overnight nonfinancial commercial paper rate, as well as the fact the TPR rate does not rise. Additionally, this quarter-end effect also induces cash investors to place additional funds at the Fed's RRP facility. Ruane (2015) shows that the amount of quarter-end movement of funds into the Fed's RRP facility essentially offsets the amount of funds coming out of G-SIB TPR funding.<sup>23</sup>

The interpretation that we have offered, highlighting the scaling back of cash-demanders' balance sheets, is argued in further detail and with more evidence by Munyan (2015). A possible alternative effect driving the end-of-quarter increase at the RRP is that money market funds also prefer to window-dress their balance sheets by shifting some assets into government paper. Although this interpretation—highlighting cash-lender incentives—is consistent with the movement in RRP and T-bill yields, it is inconsistent with the decrease in the commercial paper rate.

Munyan (2015) shows that the quarter-end reductions in bank balance sheets are most pronounced for foreign banks. Unlike U.S. banks, foreign bank compliance with SLR is monitored at the ends of quarters based on the intraquarter month-end snapshots.<sup>24</sup> U.S. banks, however comply quarterly under the “eSLR” rule, based on daily averaging within each quarter for on-balance-sheet items and averaging off-balance-sheet items at month-ends within the quarter. Indeed, in addition to large quarter-end rate effects, Munyan (2015) shows smaller but distinguishable end-of-month effects.

This evidence concerning the pass-through effects associated with the scaling back of bank and bank-dealer balance sheets at the ends of months and especially at the ends of quarters supports our hypothesis concerning the effect of increasing rates on market-equilibrium rate dispersion. We have argued that rising rates will lead to a relative drop in core bank deposits, similar to the scaling back of bank balance sheets at the ends of quarters. Following this analogy further, we would expect that, as rates rise, the spread between IOER and T-bill

rates (adjusted to overnight-equivalent rates) will fall and the volume held at the RRP facility will rise. Without additional data, it is difficult to estimate how large these effects could become. These effects will again be exacerbated at quarter-ends, at least until foreign banks begin reporting for the purpose of capital regulation on the basis of daily averaging (eSLR).

### ***VI.iii. Implications of the Liquidity Coverage Ratio Rule***

We now expand the imperfect-competition model of the previous section to analyze the implications of the liquidity coverage ratio (LCR) rule for money market equilibrium.<sup>25</sup> We are particularly interested in understanding how the LCR impinges on the supply of HQLA. The LCR requires that banks hold enough high-quality liquid assets (HQLA) to cover a stressed 30-day liquidity outflow scenario. The regulatory stress scenario varies the assumed runoff rate of deposits across the types of deposits, with a high runoff rate on wholesale deposits and a lower runoff rate on retail deposits. Categories of regulatory HQLA include U.S. Treasuries, central bank reserves, agency MBS, agency debt and other designated asset categories. The LCR assigns a preference to HQLA categories that are fully backed by the U.S. government (Tier-1 HQLA), and assigns lower liquidity weight to assets such as Fannie Mae agency debt or MBS (Tier-2 HQLA).

For modeling purposes, we suppose that banks are endowed with an aggregate stock of  $R$  in HQLA. We assume all HQLA is Tier 1. Adjusting for any risk and capital-weight considerations, the return on all HQLA held by banks must therefore be equal. For, if one particular form of HQLA offers a strictly higher return than another, then banks will hold only the higher-return HQLA. Thus if banks are holding HQLA that includes multiple types of Tier-1 assets, then all of these assets must offer the same (adjusted) return. Furthermore, because in our symmetric model all banks always hold some central bank reserves, and because these reserves are Tier-1 HQLA that pay the IOER rate of  $\phi$ , it follows that all Tier-1 HQLA must offer the return  $\phi$ . Thus, we can proceed by setting the modeled return on HQLA to  $\phi$ .

Banks invest deposits in HQLA and in a non-HQLA asset paying some return denoted  $r_L$ . For concreteness, we treat the non-HQLA asset as a bond (which may be thought of as a corporate bond or commercial paper) that is traded in a competitive market in which both banks and fast investors participate. While  $\phi$  is set by the central bank, market forces determine  $r_L$  in equilibrium. We suppose that the total supply (to modeled investors) of the non-HQLA asset is  $L(r_L)$ , where  $L(\cdot)$  is some strictly decreasing differentiable function. Thus, at higher rates, there is less borrowing and less private bond supply.

As in the model of the previous section, banks choose a deposit-rate distribution  $F$ . In addition, banks choose the fraction  $\alpha$  of raised deposits that are invested in HQLA, versus the non-HQLA fraction  $1 - \alpha$ . The LCR constraint is that banks must hold a minimum fraction  $\alpha$  of their deposits in HQLA. For simplicity, we do not distinguish between retail and wholesale deposits, so that  $\alpha$  applies equally to all deposits. Appendix B provides details on the solution of the equilibrium for this model.

There are two equilibrium cases of interest.

- 1) For some parameters, in equilibrium,  $\alpha > \underline{\alpha}$ . That is, if  $r_L$  is conjectured by market participants to be  $\phi$ , then the LCR constraint  $\alpha \geq \underline{\alpha}$  would be slack. Then, in equilibrium, it must indeed be the case that  $r_L = \phi$  because the portfolio problem for the bank, to maximize  $\alpha\phi + (1-\alpha)r_L$ , is a linear problem. This case applies whenever the total quantity  $V(g, r_L)$  of deposits that would be raised under the conjecture that  $r_L$  is equal to  $\phi$  is strictly less than the total amount  $R$  of HQLA.
- 2) With other choices for parameters, the LCR constraint is strictly binding on banks in equilibrium, implying that  $r_L > \phi$ . That is, banks reduce the amount of non-HQLA assets they choose to hold because of LCR, driving up the return  $r_L$  on non-HQLA assets to a level strictly above the return  $\phi$  on HQLA. The spread  $r_L - \phi$  is the shadow cost of the LCR constraint, which can be derived from the Lagrangian for the bank optimization problem, shown in Appendix B. When the LCR constraint binds,  $r_L$  solves the HQLA market-clearing condition:

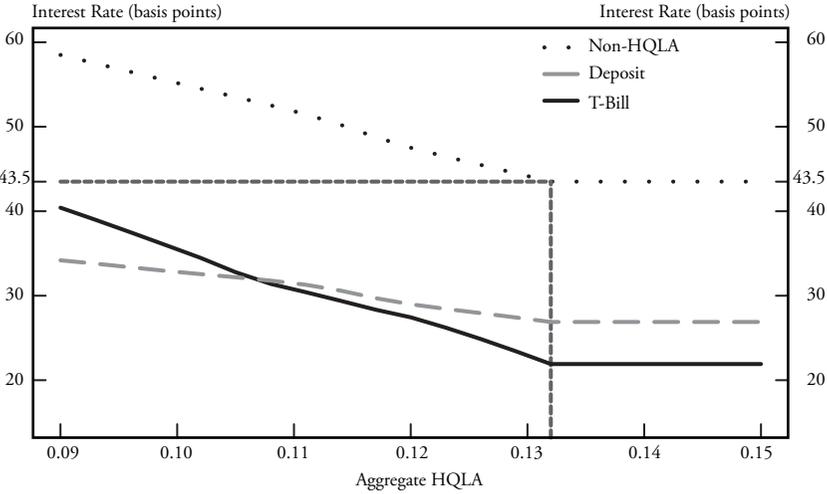
$$\alpha V(g, r_L) = R. \tag{10}$$

The first case, in which the LCR constraint is slack, corresponds to cases of the model that we have solved in previous sections. This case applies when  $R$  is sufficiently high or  $\alpha$  is sufficiently low.

Chart 13 shows the modeled responses to changes in the aggregate quantity  $R$  of HQLA of three interest rates: the non-HQLA rate  $r_L$ , the average deposit rate  $r$ , and the T-bill rate  $g$ . As shown, when  $R$  is above 0.132, indicated by the vertical black dashed line, the LCR constraint does not bind, all rates are insensitive to small changes in the quantity  $R$  of HQLA, and  $r_L = \phi$ . As  $R$  falls below this threshold level, the LCR constraint binds, raising  $r_L$ ,  $g$ , and  $r$ . The spread between  $r_L$  and the average deposit rate rises as the constraint tightens. This is natural because the LCR makes taking deposits more costly to banks, so that the spread between assets and liabilities rises. If we were to extend the plots to lower values of aggregate HQLA, the T-bill rate would rise further. The T-bill rate would never, however, rise above  $\phi$ , because T-bills count as Level-1 HQLA. That is, if  $g \geq \phi$ , banks would choose to hold T-bills as HQLA, so that the active supply of HQLA would expand beyond  $R$ .

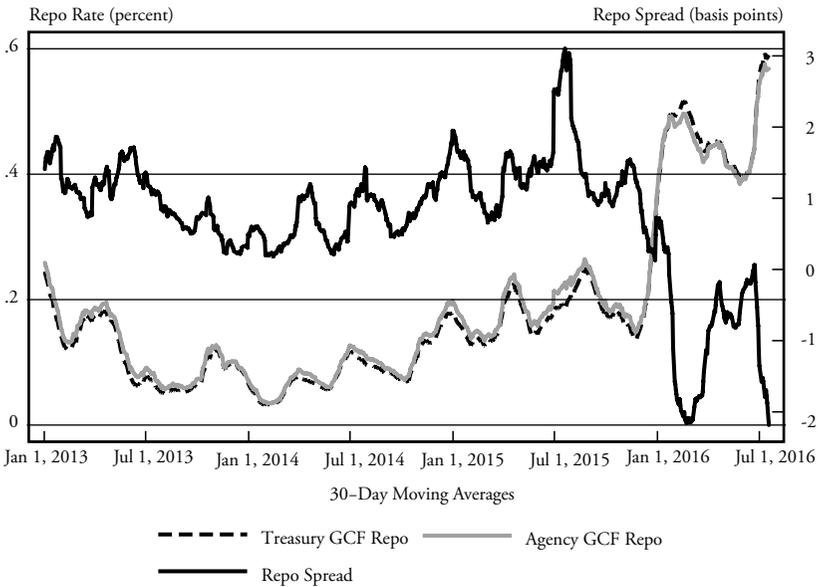
Chart 14 is a guide to whether or not LCR has recently been a binding constraint on the supply of various types of HQLA available to bank-affiliated dealers. Based on our model, the spread  $r_L - \phi$  between non-HQLA and HQLA assets is a natural metric. The chart graphs the rate on GCF repos collateralized by Treasuries and agency debt (FNMA and FHLMC), respectively. Under the LCR rule, Treasury-backed repo is a level-1 HQLA asset, whereas agency-debt backed repo is a level-2 HQLA asset, which counts with a haircut of 15 percent toward the LCR. Within our model, we can think of the level-2 HQLA as a package of 15 percent of a non-HQLA asset yielding  $r_L$  and 85 percent of an HQLA asset yielding  $\phi$ . Thus, for a dealer subject to LCR, the spread between these repo rates should reflect the shadow cost of a binding LCR constraint, and be proportional to  $r_L - \phi$ . The chart graphs the two repo rates (in percent) as well as the spread (in basis points), from Jan. 1, 2013 to June 30, 2016. The LCR constraint became operational for large U.S. bank holding companies beginning in 2015. The chart shows that the spread between these repo rates is near zero basis points and in

Chart 13



Notes: The non-HQLA rate  $r_n$ , the average deposit rate  $r$ , and the T-bill rate  $g$ , plotted against the aggregate quantity  $R$  of high quality liquid assets (HQLA). When HQLA falls below 0.132, the LCR constraint binds on all banks, driving up interest rates. These numerical examples are illustrative, and not quantitative predictions. The model parameters used to construct this chart are  $\alpha = 0.25$ ,  $R = 0.132$ ,  $w = 0.5$ , and  $W = 1.2$ , made up of bonds (0.95), T-bills (0.15), and deposits (0.1).

Chart 14



Notes: We plot the GCF repo rates (in percent) on Treasury collateral and agency-debt collateral from Jan. 1, 2013 to June 30, 2016. We also plot the spread between these repo rates (right-axis in basis points). The spreads are near zero and do not change with the introduction of the LCR in 2015. The chart suggests that currently there is no shortage of HQLA.

Data sources: DTCC and Bank of New York Mellon.

particular does not rise beginning in 2015, as one would expect to see if the LCR constraint had been binding. This absence of a significant spread thus suggests that LCR is not significantly binding on major dealers, currently.<sup>26</sup>

Other bond-market spreads could be used to detect the extent to which LCR impinges on the supply of HQLA. For banks, we may consider the spread between FNMA MBS and GNMA MBS. Banks hold both of these assets. GNMA MBS are level-1 HQLA, whereas FNMA MBS are level-2 HQLA. Thus the spread between these assets can be viewed as an increasing function of the LCR shadow price  $r_L - \phi$ . This mortgage spread, like the repo spread in Chart 14, does not increase markedly over the 2013 to 2016 period, suggesting that the LCR is not binding on the supply of HQLA. A caveat is that this spread is not a clean measure like the repo spread, because other factors such as differential prepayment risk affects the mortgage spread.

Finally, we clarify the sense of the “binding-ness” of LCR that this analysis addresses. We have shown that the LCR is not currently binding in the sense that there is a sufficient quantity of HQLA to satisfy demands induced by LCR. This leaves open, however, whether LCR forces banks to make adjustments to their portfolios that matter to their shareholders. The LCR requires banks to invest a sufficient fraction of their deposits in safe, liquid, short-term assets. A riskier asset portfolio than that forced by LCR could benefit bank shareholders at the expense of bank creditors, a standard “asset-substitution” effect. The model that we analyzed does not capture this value transfer because it treats the return of non-HQLA on a risk-free-equivalent basis, even though the otherwise-preferred non-HQLA may be risky. The LCR can thus be privately costly to bank shareholders, even in a world with abundant qualifying HQLA. At the same time, the LCR can obviously be socially beneficial by making banks safer. This other sense of “binding” is not germane to our central concern of whether LCR affects money market rate dispersion and monetary-policy pass-through.

#### ***VI.iv. Raising Rates Under the Liquidity Coverage Ratio Rule***

We have just argued that rate dispersion increases when the LCR impinges on the supply of HQLA. In this section, we discuss how LCR may interact with increases in IOER. In our model, as rates rise,

deposits fall, which in turn loosens the LCR constraint. Suppose we are in a setting in which a binding LCR gives rise to a positive spread  $r_L - \phi$  between non-HQLA and HQLA. Under these conditions, an increase in IOER reduces this spread.

Our model leaves out some considerations that are likely to be important in practice and lead to a tightening of LCR as rates rise. First, as rates rise and core bank deposits fall, banks are likely in practice to replace lost deposits with other forms of funding. Banks would likely turn to wholesale sources. But, under the LCR, wholesale funding carries a higher charge against HQLA than core bank deposits. Thus a rise in rates could make LCR more binding and increase the risk-and-term adjusted spread  $r_L - \phi$  between ordinary assets and IOER. Second, in our model and in practice, as rates rise, dispersion rises because T-bill rates and TPR repo rates fall relative to IOER. In our analysis of the RRP facility, we observed that as T-bill rates approach the RRP rate, investors shift funds into the RRP, leading to a decrease in total bank reserves, thus reducing the aggregate supply  $R$  of HQLA. This effect is likely reinforced by the activity of the nonbank sector. A rise in the spread to the HQLA rate increases the incentives of the nonbank sector to engage in liquidity and maturity transformation.

As a specific example of this, a securities dealer could buy long-term Treasuries financed on repo. The repo could be held by a government MME, which issues claims to investors, providing them with liquidity services. As rates rise and fast investors move funds out of bank deposits and into government MME, there is an increased demand for long-term Treasuries to collateralize repos. Suppose that, before a rise in rates, banks satisfy LCR by holding a combination of central-bank deposits and long-term Treasuries, as currently seems to be the case. Then, as demand for long-term Treasuries rises, their prices rise and buying them becomes less attractive as a way satisfy the LCR for banks. If the return on Treasuries falls below  $\phi$ , banks will no longer hold them to meet the LCR. T-bill rates have been trading at rates well below IOER, so banks have little current incentive to own T-bills in order to meet the LCR. Thus, the effective supply of HQLA to banks would shrink in this case, tightening LCR.

These considerations imply that in a rising rate environment, the LCR constraint, which does not seem to have a significant effect on the current market equilibrium, may come to affect equilibrium rates. Dispersion would then rise, and the pass-through of monetary policy to other money market rates would be reduced.

For a regulatory, debt management, or monetary policy to offset this effect, it would need to expand the effective supply of safe assets available to cash investors, or increase the effective supply of HQLA available to banks. A standard open market operation—a purchase of Treasury notes and expansion of reserve balances—would not help because both reserves and Treasury notes are Level-1 HQLA. Swapping one of these two assets for the other leaves total Level-1 HQLA unchanged. For the Fed to ease the HQLA scarcity, it would need to purchase a Level-2 HQLA, such as an FNMA MBS, and expand bank reserves. The Fed could also purchase agency MBS and reverse them out through the RRP facility. This does not reduce total Fed HQLA, and provides investors with more of the safe liquid assets that they would demand in response to an increase in IOER.

## **VII. Money Market Fund Reform**

To address the fragility of prime money market mutual funds that was revealed during the financial crisis, the SEC has tightened the rules on these funds. Beginning October 2016, institutional prime and municipal funds will switch from a constant net asset value (CNAV) format to a form based on floating net asset values. Further, when these types of funds are under stress, investors in nongovernment funds could face liquidity fees and redemption gates. Government-only money funds continue in the more popular CNAV format, without liquidity fees or gates. Prime money funds have been significant buyers of private paper, including commercial paper, bank CDs and eurodollar deposits. The SEC rule changes are already causing a heavy reduction in the assets of institutional prime funds relative to government-only funds. Based on data provided by the Investment Company Institute, \$420 billion has already moved from prime funds to government funds.<sup>27</sup> Many observers expect that investors will continue this shift.

Although they add to financial stability, these rule changes will likely increase dispersion in money market rates because they drive up the demand for government paper relative to private paper.<sup>28</sup> Prime funds are also shifting their portfolios toward lower-risk and shorter-term assets, including government paper, because they will soon have floating net asset values and some money-fund clientele are averse to volatile returns.

Likely as a response to this shift out of longer-term unsecured paper, between May 1, 2016 and July 27, 2016, three-month LIBOR rose over 10 basis points, while IOER remained constant.<sup>29</sup> In the context of our modeling, these reforms are akin to a reduction in the supply of T-bills. That is, the effect of the rule change is to reduce the supply of deposit alternatives, which previously included both T-bills and constant-net-asset-value money funds that invested in both government paper and private paper. Our model and empirical analysis suggest that reducing the effective supply of T-bills decreases T-bill rates and Treasury-backed repo rates. The MMF rule change will also place pressure on the supply of short-term HQLA. As more money-fund assets shift to government quality, the demand for government paper including the RRP will rise. With rising RRP take-up, bank-held reserves will automatically fall, reducing the effective supply to banks of short-term HQLA and potentially causing the LCR constraint to bind.

### **VIII. Pass-Through Reliance on Repo Market Infrastructure**

The pass-through of Fed policy rates into the repo market is critical to the performance of U.S. monetary policy. The repo market is a large core market for short-term financing and cash investment, in addition to its key role in facilitating the financing and intermediation of securities, and thus pass-through of monetary policy into bond yields. Further, the repo rates achieved on high-quality collateral have historically been the available best source of price discovery for risk-free overnight U.S. interest rates. In the new monetary policy setting, FFER is not an effective source of price discovery.<sup>30</sup> The Fed has shown a strong interest in better alternative interest-rate benchmarks, including an overnight repo-rate benchmark.<sup>31</sup>

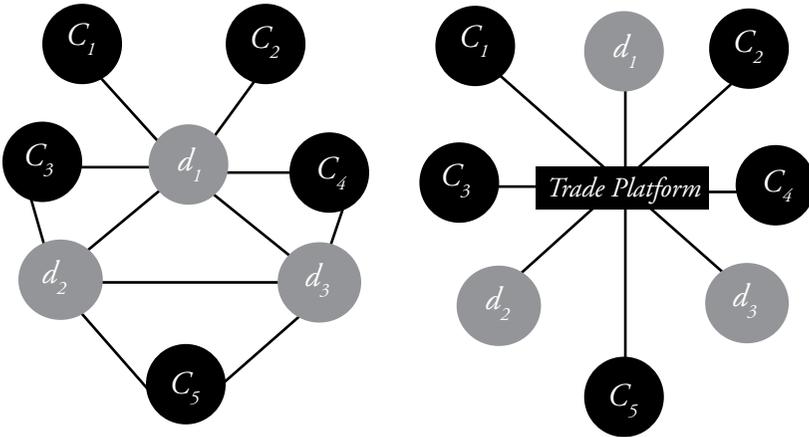
The infrastructure for the U.S. repo market is not currently effective at promoting pass-through efficiency. We have shown how various repo rates are not well integrated with each other, and often differ significantly from IOER and the RRP rate. For example, GCF (interdealer) Treasury repo rates are now much higher than tri-party Treasury repo rates. Indeed, GCF rates are recently even above IOER on quarter-ends. TPR rates are closer to, but not equal to, RRP rates.

In addition to the potential benefits of a new repo-rate benchmark, there are opportunities to improve pass-through through improvements in repo-market infrastructure in three areas: trade-execution venues, central counterparties and TPR clearing technology.

First, as in the schematic shown in Panel A of Figure 2, the lion's share of repos are intermediated by primary dealers. As we have explained, this requires heavy use of space on balance sheets that are subject to capital regulation, in particular the SLR rule, which has driven repo bid-offer spreads dramatically wider. Greater use of direct-repo or multilateral trade platforms, as illustrated in Panel B of Figure 2, would economize on the use of balance sheet space of the primary dealers. In Europe, according to ICMA European Repo and Collateral Council (2015), direct repo platforms and anonymous automatic trading systems (ATS) handle nearly half of all trade, which is far more than in the U.S. (Most of this European platform trade, however, is still intermediated by banks.)

Second, as illustrated in Panel A of Figure 3, the U.S. government securities repo market still relies on a narrow interdealer repo central counterparty (CCP), the Fixed Income Clearing Corporation (FICC). A broad-market CCP would include as clearing members a range of buy-side firms, such as money market funds, pension funds, insurers and hedge funds. Various attempts to introduce a broad-market CCP, as illustrated in Panel B of Figure 3), have not yet been successful. A broad-market CCP would allow more scope for long and short positions intermediated by primary dealers to be offset through multilateral netting at the CCP, thus reducing the use of balance sheet space. Again, the SLR is especially implicated.

**Figure 2**  
**Two Approaches to Intermediation of the Repo Market**



A. Without trade platforms, for most trades, at least one counterparty is a primary dealer. Dealers lay off some positions with other dealers. In-termediation of the market thus in-volves heavy aggregate use of dealer balance sheets.

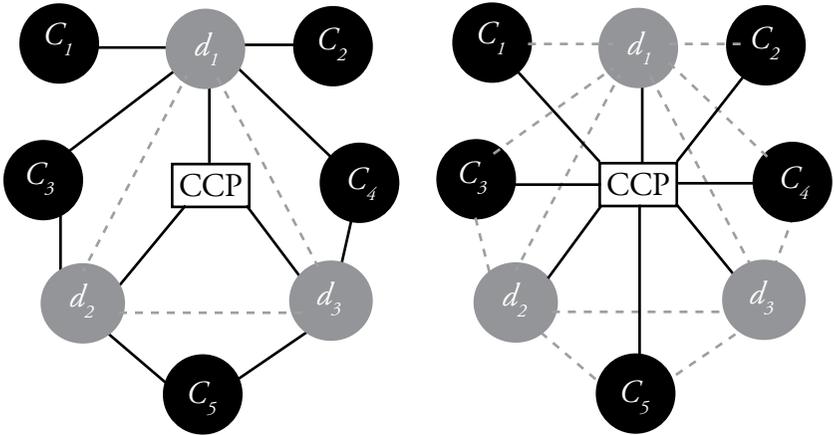
B. The subset of repo trades conducted on a multilateral or other direct-trade platform. Firms that are not primary dealers are more able to trade directly with each other. In-termediation of the market requires lighter use of dealer balance sheets.

Notes: Panel A shows a market in which all trades are executed with one of the dealers,  $d_1$ ,  $d_2$ , or  $d_3$ . Panel B shows the subset of trades that are executed on a trade platform, whether multilateral or "direct trade." These trades may or may not be centrally cleared, depending on the setting. With or without central clearing, there is a greater opportunity for nondealers to trade directly with nondealers. For example,  $c_1$  can trade directly with  $c_5$ . This reduces the aggregate amount of dealer balance sheet required to intermediate the market. Especially under SLR, this reduces intermediation frictions and improves pass-through.

The beneficial effects of repo trade platforms and CCPs, shown in Panel B of Figures 2 and 3, respectively, are related, but not the same. Repo trade platforms allow some disintermediation of dealers, by allowing ultimate buyers and sellers to trade directly with each other. Broad-market CCPs allow more scope for multilateral netting after trades are executed, thus reducing the amount of balance sheet space that dealers need to intermediate a given amount of trade.

The key impediment to the introduction of a broad-market repo CCP has been the liquidity commitments necessary to safely manage the larger amounts of collateral that would be held by a broad-market CCP, in the event that one or more clearing members fail. In principle, the additional liquidity would need to be committed in advance, in some combination, by the nondealer clearing

**Figure 3**



A. A narrow interdealer CCP. Dealers  $d_1, d_2$ , and  $d_3$  centrally clear their trades with each other. Positions of dealers with counterparties that are not clearing members,  $c_1, c_2, c_3, c_4$  and  $c_5$ , remain on the balance sheets of dealers.

B. Role of broad-market CCP. For example, the positions of  $d_1$  with  $c_1, c_2, c_3$ , and  $c_4$  can also be novated to the CCP, further reducing the balance sheet space of  $d_1$  required to in-terminate the repo market.

Notes: Original repo trades that were subsequently novated to the CCP are shown in dotted lines. Through this novation, known as “central clearing,” the CCP becomes the buyer to each original seller, and the seller to each original buyer. With an interdealer repo central counterparty (CCP), as shown in Panel A, a securities dealer such as  $d_1$  novates to the CCP its trades with other dealer clearing members,  $d_2$  and  $d_3$ , thus reducing its gross outstanding positions and use of balance sheet space, through the effect of netting long against short positions. This is also systemically safer (assuming the CCP is sound). Positions with counterparties that are not clearing members, such as  $c_1, c_2, c_3$ , and  $c_4$ , remain on the balance sheet of  $d_1$ . With a broad-market repo CCP, as shown in Panel B, more positions can be novated to the CCP, thus further reducing the use of space on dealers’ balance sheets. This mitigates the cost of repo intermediation to dealers’ shareholders for meeting regulatory capital requirements, especially under the Supplementary Leverage Ratio Rule.

members, the CCP operator, the dealer clearing members or the Federal Reserve (as a lender of last resort). So far, despite attempts, a solution has not been found, but the Depository Trust & Clearing Corp. has indicated it plans to open such a service in 2017.<sup>32</sup>

Finally, despite significant post-crisis improvements in the stability of TPR market infrastructure that were spurred by the Federal Reserve Bank of New York, some fragility remains.<sup>33</sup> Moreover, one of the two main tri-party clearing banks, JPMorgan Chase, has declined to make some of the improvements in its clearing technology necessary to handle trades that are centrally cleared by FICC and which involve a counterparty whose tri-party clearing bank is BNY Mellon. Since June 2016, “cross-bank” trades of this type are no longer possible. This bifurcation of FICC trades has effectively created two almost separate interdealer “GCF” repo markets. Immediately

after the bifurcation, BNY Mellon GCF repo rates were said to be several basis points lower than JP Morgan Chase GCF repo rates.<sup>34</sup> Soon afterward, on July 21, 2016, JPMorgan Chase announced that, beginning in July 2018, it no longer would handle TPR clearing that arises in the setting of FICC GCF repo.<sup>35</sup>

Frictions in the movement of collateral through the TPR market, whether arising from inefficient collateral allocation at a given bank or bifurcation of collateral across clearing banks, dampens pass-through of monetary policy into the repo market. Along these lines, Ruane (2015) of BNY Mellon writes that “we expect the next market evolution to result in a more seamless movement of collateral, culminating with the linkage of international central security depositories and more integrated global operations of market participants.”

We also note that the Fed’s RRP facility rests operationally on the TPR market’s clearing infrastructure.

## **IX. Concluding Remarks**

We have argued that, currently, the pass-through of the Fed’s monetary policy target rates into U.S. money markets is impaired mainly by imperfect competition for bank deposits and by the SLR rule. Because of imperfect competition, banks increase their deposit rates less than one for one with increases in the rate they are paid by the Fed on IOER. The SLR raises the cost of balance-sheet space for intermediation of repo markets, and has driven a large wedge between the rates available in different segments of the repo market.

The Fed’s RRP facility improves pass-through, mainly by offering money funds a substitute for bank deposits and T-bills, at a rate chosen by the Fed. At least in our model, the main pass-through benefit is achieved through disintermediation of banks, which pulls “fast” depositors into T-bills and money funds. The RRP facility therefore increases the average stickiness of the remaining depositors, and can actually reduce pass-through into bank deposit rates. We suggest that this selection effect on pass-through could become more severe as the Fed’s target rates rise.

Charts 3 and 4 show that dispersion in money market rates rose noticeably in December 2015, at the very first pass-through event of the Fed's new monetary policy setting. When the Fed increased IOER by 25 basis points and the RRP rate by 20 basis points, our measure of dispersion immediately increased by more than 10 basis points. (Our dispersion metric is the weighted mean absolute deviation across private-sector money market rates, on an overnight-equivalent basis.)

Looking forward, based on our calculations, although the LCR does not currently impinge on the supply of HQLA, a sufficient increase in rates could cause LCR to bind on the stock of short-term HQLA, increasing rate dispersion. Likewise, rate dispersion is already being pushed higher by the new money market fund rules that take effect in October 2016. We expect that take-up at the RRP facility will rise as rate dispersion rises.

We explain how these pass-through inefficiencies can be mitigated by an increase in the supply of T-bills (or substitutes, such as Fed segregated balance accounts), by improvements in repo market infrastructure that allow the market to operate with less intensive use of dealer balance sheets, and by a modification of the SLR rule.

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## Appendix A

### Data Used for Rate Dispersion Measures

This appendix summarizes the data and approximations used to construct our measures of rate dispersion. Unless otherwise stated, the following data series are available from January 2002 until June 2016. Due to data limitations, our current construction is relatively crude, and should be viewed as providing only a rough guide to actual money market dispersion, and perhaps as a template for improved measures that could be obtained with the benefit of more data. Daily data series are averaged to form a weekly time series, from which the dispersion index, and percentiles of the cross-sectional rate distribution, are finally calculated.

#### *A.1 Jumbo Time Deposits*

After June 2009, one-month rates for “jumbo” certificates of deposit (CDs) are obtained daily from the Federal Reserve Economic Data (FRED) website of the Federal Reserve Bank of St. Louis.<sup>36</sup> Prior to this date, we use instead the one-month CD secondary market rate (daily), also from FRED. For consistency, we estimate and adjust for means using the overlapping sample from June 2009 to June 2013. We use the FRED series for “large time deposits” to estimate the volume of jumbo time deposits.

#### *A.2 Commercial Paper*

Daily data of overnight AA rated financial and nonfinancial commercial paper rates are from FRED. Weekly total volumes outstanding for the series are also provided by FRED. The flight from financial commercial paper (CP) during the financial crisis sharply raised financial CP rates. Because this would have contaminated our dispersion index with credit spreads, we proxied financial CP rates with nonfinancial CP rates, treating the entire CP market as though it traded at the rates observed for nonfinancial CP.

#### *A.3 GCF (Interdealer) Repos*

GCF repo rate data for repos collateralized by MBS, Treasuries and agency notes, respectively, are available from the website of DTCC,

but only from January 2005.<sup>37</sup> We are unable to locate GCF pricing data prior to March 2005. Thus, prior to March 2005, our dispersion measures do not include the effect of GCF repo. Beginning in 2016, GCF repo rates are no longer available to us from DTCC, and were obtained instead from Bloomberg. (During periods when GCF repo rate data are available from both Bloomberg and DTCC, the two sources match.)

Volume data beginning in May 2011 are obtained from the website of the Federal Reserve Bank of New York.<sup>38</sup> For volumes prior to May 2011, we approximated as follows. For the period when GCF volumes and primary dealer repo financing (New York Fed) are both available, we regress the former onto the latter to obtain predicted GCF volumes. A similar approximation method is used by Copeland, Martin and Walker (2010).

#### ***A.4 Tri-Party Repos***

Rates for TPRs collateralized by MBS, Treasury and agency debt repos, respectively, can be found on the website of BNY Mellon.<sup>39</sup>

The mortgage backed and agency series are weighted and combined to be consistent with the earlier sample from Krishnamurthy, Nagel and Orlov (2014) covering October 2006 until April 2010.

Starting in May 2010, volume data is provided by the New York Fed. Volumes from July 2008 until January 2010 are extracted from the plots in Copeland, Martin and Walker (2010). Finally, we regress available TPR volumes on primary dealer repo financing (New York Fed) to obtain fitted values for the missing sample. Again, we use the approximation suggested by Copeland, Davis, LeSueur and Martin (2012).

#### ***A.5 Eurodollar Deposits***

Data on overnight eurodollar deposit rates are from FRED, and are based on one-day LIBOR.<sup>40</sup> Volumes prior to February 2006 are accessible via FRED. For every week in the later sample, we linearly regress available eurodollar volumes on total bank liabilities (FRED) to obtain fitted values for the missing dates.

## ***A.6 Treasuries***

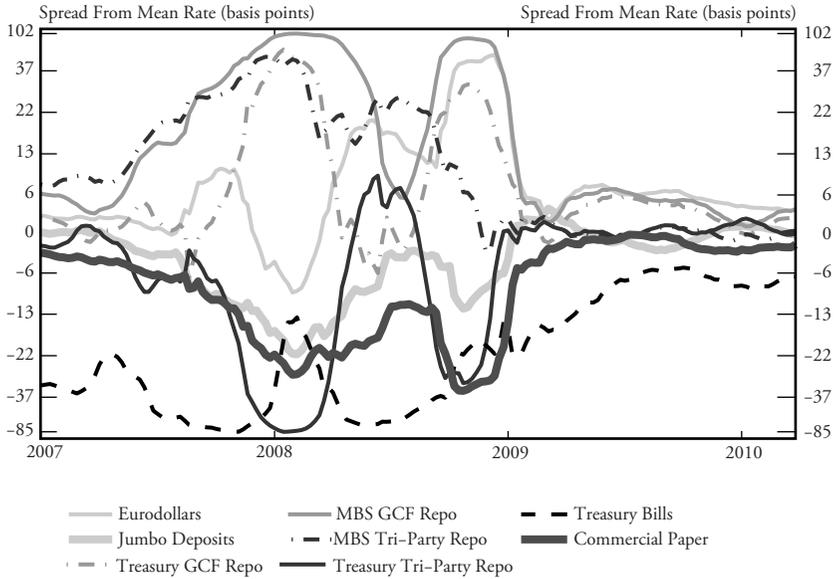
One-month Treasury bill rates are from FRED. One-week rates are obtained by linearly interpolating (by maturity) T-bill rates obtained from the Center for Research in Security Prices (CRSP) database. For construction, we first obtain, for every day, all outstanding T-bill issues from CRSP. We select issues into segments with remaining maturities of one-10 days and 11-40 days. After taking the weekly mean, the volume is scaled by the ratio of T-bills held by the public to T-bills listed in CRSP, to account for missing observations in CRSP. The monthly amount of T-bills held by the public are obtained from the Treasury Direct website.<sup>41</sup>

Some results are based on data back to 1954. We obtain the three-month Treasury bill rate from FRED. We use the total amount of T-bills outstanding, without reference to maturity, from the U.S. Treasury website.

## ***A.7 A Further Adjustment to Overnight Unsecured Rates***

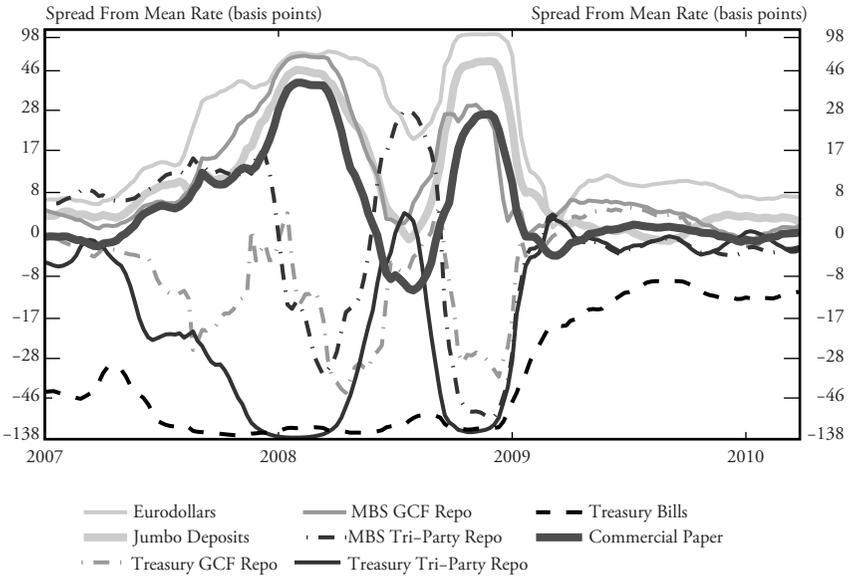
Because of lack of data, we are unable to make a final adjustment to unsecured rates for the difference between a benchmark for overnight major-bank unsecured rates and a benchmark secured overnight rate. While this spread is normally small, it includes some “quality” effects that are not caused only by market imperfections. For example, there is a flight to quality during the financial crisis that reflects, to some degree, credit risk and aversion to credit risk. Chart A.1 shows the effect of making this additional adjustment during a subperiod of the sample for which we have some relevant data. For this period, we subtract from each unsecured rate (after other adjustments for term and term credit effects) the spread  $u(t) - s(t)$  between an unsecured overnight “benchmark” rate  $u(t)$  and a secured overnight “benchmark” rate  $s(t)$ . For  $u(t)$ , we use the average of the eurodollar rate and FFER. For the secured rate  $s(t)$ , we used the average of the rates on Treasury GCF repo and Treasury TPR. Because of lack of availability of these repo rates throughout the sample, we restrict attention to a subperiod of the sample covering the financial crisis.<sup>42</sup> For comparison, Chart A.2 shows the same rates during the same subperiod of the sample, before this additional adjustment of overnight-equivalent unsecured rates for the spread  $u(t) - s(t)$ .

Chart A.1



Notes: The cross-sectional distribution of overnight-equivalent money-market rates, as rolling 90-day lagging averages, after adjusting each unsecured rate by subtracting the spread  $u(t) - s(t)$  between an unsecured overnight “benchmark” rate  $u(t)$  and a secured overnight “benchmark” rate  $s(t)$ . For  $u(t)$ , we use the average of the eurodollar rate and FFER. For the secured rate  $s(t)$ , we used the average of the rates on treasury GCF repo and Treasury tri-party repo. Because of lack of availability of the repo rates throughout the sample, we restrict attention to a subperiod of the sample covering the financial crisis. The underlying rates included in this analysis are as described in the text and legend, and are shown net of simple adjustments for credit and term premia described in the text. The line weight of a given rate is proportional to the average outstanding quantity of the instrument over the period in which it is present in the sample. The vertical scale is “stretched” near median levels, relative to tail levels, with a nonlinear rescaling given by the students-t distribution with 3 degrees of freedom. Thus, the equally spaced tick marks on the vertical axis are separated by an unequal number of basis points, as shown. This plot is extremely preliminary.

**Chart A.2**



Notes: The cross-sectional distribution of overnight-equivalent money-market rates, as rolling 90-day lagging averages, before adjusting each unsecured rate by subtracting the spread between an unsecured overnight “benchmark” rate and a secured overnight “benchmark” rate. The underlying rates included in this analysis are as described in the text and legend, and are shown net of simple adjustments for credit and term premia described in the text. The line weight of a given rate is proportional to the average outstanding quantity of the instrument over the period in which it is present in the sample. The vertical scale is “stretched” near median levels, relative to tail levels, with a nonlinear rescaling given by the students-t distribution with 3 degrees of freedom. Thus, the equally spaced tick marks on the vertical axis are separated by an unequal number of basis points, as shown. This plot is extremely preliminary.

## Appendix B

### Technical Details: Imperfect-Competition Model

This appendix provides technical details for the theoretical model of imperfect competition.

#### *B.1 Basic Model*

We first solve for fast investors' portfolio choice problem:

$$\max_{b, f, t} b(1+r^*) + f(1+h) + t(1+g) + K \log(b) + k \log(f+t)$$

$$\text{subject to } b + f + t \leq W$$

where we recall that  $r^* = \max\{r_1, \dots, r_N\}$  is the highest deposit rate available,  $h$  and  $g$  are interest rates on MMFs and T-bills, respectively.

As we have assumed that MMFs are government funds that invest only in T-bills, and that MMFs and T-bills are indistinguishable from the viewpoint of investors,  $h$  and  $g$  are identical in equilibrium. For simplicity, we write  $t$  as the sum of investment in MMFs and investment in T-bills by fast investors. The first order condition for a fast investor's portfolio choice problem is

$$r^* - g + \frac{K}{b} - \frac{k}{W-b} = 0 \tag{B.1}$$

We let  $D(r^*; g)$  denote the unique solution to equation (B.1) that satisfies  $0 < D(r^*; g) < W$ .

Banks value deposits at the all-in shadow rate  $\phi$ . As we explained in Section V.i, in any equilibrium, a bank will offer deposit rates from a continuous cumulative distribution function (CDF), denoted  $F$ . The intuition for this result is that bank profits could be discretely increased by undercutting atoms, so that the optimal quote distributions must have no atoms. Like Stahl (1989), we restrict attention to symmetric equilibrium.

We let  $F(r; g, \underline{r})$  denote the CDF of bank deposit rates, whose support is an interval with lower support point  $\underline{r}$ . As we have shown in Section V.i,  $F(r; g, \underline{r})$  satisfies:

$$\left[ \mu F(r; g, \underline{r})^{N-1} D(r; g) + \frac{1-\mu}{N} w \right] (\phi - r) = \frac{1-\mu}{N} w (\phi - \underline{r}) \quad (\text{B.2})$$

By imposing the adding-up constraint that  $F(\bar{r}; g, \underline{r}) = 1$ , the upper support point  $\bar{r}$  solves

$$D(\bar{r}; g) = \frac{1-\mu}{\mu N} w (\bar{r} - \underline{r}),$$

which is uniquely determined.

Now, we characterize  $\underline{r}$  and provide conditions under which equilibrium exists. From the solution to the Pandora problem, for the slow investor to be indifferent to search when quoted a deposit interest rate of  $\underline{r}$ , it must be that there is a net value of zero to the depositor of giving up the opportunity to deposit at  $\underline{r}$  and instead expending one more search cost  $c$  and accepting the next bank's deposit rate offer, which is drawn with the distribution  $F(r; g, \underline{r})$ . The surplus value to the slow depositor of giving up the rate  $\underline{r}$  and receiving a new rate offer is

$$G(\underline{r}) \equiv w \int_{\underline{r}}^{\bar{r}(\underline{r})} (r - \underline{r}) dF(r; g, \underline{r}) = w \int_{\underline{r}}^{\bar{r}(\underline{r})} (1 - F(r; g, \underline{r})) dr. \quad (\text{B.3})$$

For simplicity, we let  $\Psi(r; g) \equiv D(r; g)(\phi - r)$ , and we let  $\hat{r}(g) \equiv \text{argmax } \Psi(r; g)$ . It can be checked that  $\hat{r}(g)$  exists and that  $\Psi(r)$  is decreasing in  $r$  for  $r > \hat{r}(g)$ .

Now, we prove the following result monotonicity result for  $G$ .

**Lemma 1.**  $G(\underline{r})$  is decreasing in  $\underline{r}$  for any  $\hat{r}(g) \leq \underline{r}$ .

*Proof.* We know that

$$\frac{dG(\underline{r})}{d\underline{r}} = \frac{d \int_{\underline{r}}^{\bar{r}(\underline{r})} w dr}{d\underline{r}} - \frac{d \int_{\underline{r}}^{\bar{r}(\underline{r})} w F(r; g, \underline{r}) dr}{d\underline{r}}.$$

It is easy to see that

$$\frac{d \int_{\underline{r}}^{\bar{r}(\underline{r})} w dr}{d\underline{r}} = -w + w \frac{d\bar{r}(\underline{r})}{d\underline{r}},$$

and

$$\frac{d \int_{\underline{r}}^{\bar{r}(\underline{r})} w F(r; g, \underline{r}) dr}{d\underline{r}} = w \frac{d\bar{r}(\underline{r})}{d\underline{r}} + \int_{\underline{r}}^{\bar{r}(\underline{r})} w \frac{\partial F(r; g, \underline{r})}{\partial \underline{r}}.$$

Notice that

$$\frac{\partial F / \partial \underline{r}}{\partial F / \partial r} = \frac{w \Psi(r)}{w \Psi(r) - w(r - \underline{r}) \Psi'(r)}.$$

As a result,

$$\frac{d \int_{\underline{r}}^{\bar{r}(\underline{r})} w F(r; g, \underline{r}) dr}{d\underline{r}} = w \frac{d\bar{r}(\underline{r})}{d\underline{r}} - \int_{\underline{r}}^{\bar{r}(\underline{r})} w \frac{w \Psi(r)}{w \Psi(r) - w(r - \underline{r}) \Psi'(r)} dF(r; g, \underline{r}).$$

Thus,

$$\frac{dG(\underline{r})}{d\underline{r}} = -w + w \int_{\underline{r}}^{\bar{r}(\underline{r})} \frac{\Psi(r)}{\Psi(r) - (r - \underline{r}) \Psi'(r)} dF(r; g, \underline{r}) < 0,$$

where the last inequality is due to the fact that  $\Psi'(r) < 0$  for any  $r \geq \hat{r}(g)$ .

The next result is a direct implication of Lemma 1.

**Lemma 2.** For any search cost  $c \in [0, G(\hat{r}(g))]$  there is an unique  $r \leq \phi$  that satisfies

$$c = G(\underline{r}) = w \int_{\underline{r}}^{\bar{r}(\underline{r})} (r - \underline{r}) dF(r; g, \underline{r}). \tag{B.4}$$

Given the T-bill rate  $g$ , the total amount of deposits raised by banks is

$$V(g) = \mu \int_{\underline{r}}^{\bar{r}(\underline{r})} D(r; g) dF^N(r; g) + (1 - \mu)w. \tag{B.5}$$

The T-bill rate  $g$  solves the market clearing condition,

$$(1 - \mu)w + \mu W - V(g) = \frac{S}{1 + g}. \quad (\text{B.6})$$

We thus have the following result.

**Proposition 1.** *There exists a unique equilibrium corresponding to the quantities  $g$ ,  $r$ , and  $F(r; g, r)$  defined by equations (B.2), (B.4), and (B.6) provided that the search cost  $c$  is no greater than  $G(\hat{r}(g))$ .*

From now on, for a given T-bill rate  $g$ , we restrict attention to cases in which the search cost  $c$  is no greater than  $G(\hat{r}(g))$ . For notational simplicity, we let  $g_0$  denote the T-bill rate determined by equations (B.2), (B.4), and (B.6).

### ***B.2 Introducing the RRP Facility***

Now, we introduce the RRP facility offering a rate  $\rho_0 \leq \phi$ . As we have assumed that the MMFs shares and T-bills are perfect substitutes for fast investors, the T-bill rate  $g$  is at least as high as the RRP rate  $\rho_0$ . Otherwise, MMFs will invest in O/N RRP rate, and offer a rate to depositors higher than the T-bill rate and the T-bill market would not clear. In other words, the RRP rate  $\rho_0$  is a floor rate for T-bill rate in our model.

The following results describe the market equilibrium. The proof is essentially the same as that in the previous section, except for the different market clearing condition for T-bills.

**Proposition 2.** *If  $\rho_0 \leq g_0$  then  $(g_0, r(g_0), F(r; g_0, r(g_0)))$  specify a unique symmetric equilibrium. In this case, the RRP volume is zero. Moreover, if  $\rho_0 > g_0$  then  $(\rho_0, r(\rho_0), F(r; \rho_0, r(\rho_0)))$  defined by equations B.2 and B.4 specify a unique symmetric equilibrium. In this case,  $V(\rho_0)$  is invested in bank deposits and  $(1 - \mu)w + \mu W - V(\rho_0) - S/(1 + \rho_0)$  is invested in RRP through money funds.*

### ***B.3 Details for the LCR-Extension of the Model***

For the LCR version of the model, we have the following details.

*Bank's problem:* Given  $r_L$ , a bank chooses  $F$  to satisfy:

$$\left[ \mu F(r)^{N-1} D(r; g, b, r_L) + \frac{1-\mu}{N} w \right] (\alpha \phi + (1-\alpha) r_L - r) = \frac{1-\mu}{N} w (\alpha \phi + (1-\alpha) r_L - \underline{r}). \quad (\text{B.7})$$

and chooses  $\alpha$  to maximize,

$$\alpha \phi + (1-\alpha) r_L, \quad (\text{B.8})$$

subject to the LCR constraint  $\alpha \geq \underline{\alpha}$ .

*Depositor's problem:* We modify the depositor side of the model slightly as well. Slow depositors remain the same, with an endowment of  $w$ , which we assume to consist of deposits  $w$  in banks. Fast depositors are endowed with deposits, T-bills and the non-HQLA asset. They have a total endowment of  $W$ , consisting of all T-bills and corporate bonds ( $\frac{S}{\mu}$  T-bills, and  $\frac{L}{\mu}$  corporate bonds), with the remainder in deposits.<sup>43</sup> Fast depositors solve

$$\max_{b, f, g} b(1+r^*) + f(1+h) + t(1+g) + l(1+r_L) + K \log(b) + k \log(f+t)$$

$$\text{subject to } b + f + t + l \leq W,$$

where  $b, f, t$  and  $l$  are the amounts of funds placed in bank deposits, MMFs, T-bills and corporate bonds, respectively; and where  $h, g$  and  $r_L$  are the equilibrium interest rates on MMFs, T-bills, and the corporate bond. We note that holdings of corporate bonds do not provide any convenience utility to the depositor.

As before, our assumption that T-bills and MMFs are perfect substitutes implies that  $h = g$ . Given the T-bill rate  $g$  and non-HQLA rate  $r_L$ , the total demand for deposits is

$$V(g, r_L) = \mu \int_{\underline{r}}^{\bar{r}} D(r; g, g, r_L) dF_g^N(r) + (1-\mu)w. \quad (\text{B.9})$$

Market clearing conditions: The demand for HQLA must equal to the supply of HQLA:

$$\alpha V(g, r_L) = R. \quad (\text{B.10})$$

Given an exogenously supplied face value  $S$  of T-bills, the T-bill rate  $g$  is then determined by equating the market values of T-bills demanded and supplied:<sup>44</sup>

$$(1 - \mu)w + \mu W - V(g, r_c) - \mu l(g, r_L) = \frac{S}{1 + g}, \quad (\text{B.11})$$

The demand for the non-HQLA asset must equal to the supply of the non-HQLA asset:

$$\mu l(g, r_L) + (1 - \alpha)V(g, r_L) = \frac{L}{1 + r_L}. \quad (\text{B.12})$$

The T-bill rate  $g$  and bond rate  $r_L$  solving these equations and the corresponding deposit rate distribution  $F_{g, r_L}$  and HQLA choice  $\alpha$  constitute an equilibrium under technical conditions on the primitive parameters  $(c, \mu, k, K, W, w, S, L)$ . These technical conditions are satisfied in all of our numerical examples.

Fast investors always place some positive amounts in bank deposits and T-bills due to their liquidity benefits. Thus, there are three possibilities:

- If  $r_L \leq \max\{r^*, g\}$ , then  $l = 0$ , and  $(b, t)$  satisfies

$$r^* - g + \frac{K}{b} - \frac{k}{W - b} = 0, \quad (\text{B.13})$$

and

$$b + t = W. \quad (\text{B.14})$$

- If  $r_L > \max\{r^*, g\}$ , and  $W \leq Kl(r_L - r^*) + k(g - r^*)$ , then  $l = 0$ , and  $(b, t)$  is determined by equations B.13 and B.14.
- If  $r_L > \max\{r^*, g\}$  and  $W > Kl(r_L - r^*) + k(g - r^*)$ , then

$$b = \frac{K}{r_L - r^*}, \quad t = \frac{k}{r_L - g}, \quad \text{and } l = W - \frac{K}{r_L - r^*} - \frac{k}{r_L - g}.$$

We let  $D(r^*; g, r_L)$  and  $L(r^*; g, r_L)$  denote the solutions  $b$  and  $l$  to a fast investor's portfolio choice problem. The aggregate amounts invested in bank deposits and corporate bonds are

$$V(g, r_L) = \mu \int_{\underline{r}}^{\bar{r}} D(r; g, r_L) dF^N(r; g, r_L) + (1 - \mu)w,$$

and

$$\mu l(g, r_L) = \mu \int_{\underline{r}}^{\bar{r}} L(r; g, r_L) dF^N(r; g, r_L)$$

respectively, where  $F(r; g, r_L)$  is determined by

$$\left[ \mu F(r; g, r_L)^{N-1} D(r; g, r_L) + \frac{1-\mu}{N} w \right] (\alpha\phi + (1-\alpha)r_L - r) = \frac{1-\mu}{N} w (\alpha\phi + (1-\alpha)r_L - \underline{r}).$$

## Endnotes

<sup>1</sup>See Hannan and Berger (1991), Neumark and Sharpe (1992), Diebold and Sharpe (1990), Craig and Dinger (2011), Yankov (2014), Driscoll and Judson (2013) and Drechsler, Savov and Schnabl (2016).

<sup>2</sup>Anecdotally, we understand from conversations with market participants that bid-ask spreads for Treasury repo intermediation are now in the range of 15 points to 20 points, having increased from their pre-SLR levels of around 2 basis points.

<sup>3</sup>For example, DRX Direct Repo offers both platform based and bilateral OTC trade matching, with an average daily repo balance of approximately \$100 billion, according to its own reporting.

<sup>4</sup>Of course, this cash does not come out of thin air; homeowners reduce their bank deposits over the course of the month and mortgage investors see corresponding increases in their cash balances at the end of the month. If the money market had no segmentation, then this reallocation of cash would have little effect on market equilibrium. Yet, it is clear in the data that movements in the TPR track the GSE cash cycle closely. The repo rate tends to fall in the middle of the month and rise later in the month. This phenomenon is direct evidence of the importance of market segmentation.

<sup>5</sup>Cipriani and Gouny (2015) provide institutional details on this market.

<sup>6</sup>According to Fed data presented by Potter (2016), eurodollar deposits have recently ranged between \$200 billion and \$250 billion, whereas federal funds have totaled around \$75 billion, most of which is deposited by GSEs, who do not receive IOER on their federal reserve deposits. Pozsar and Smith (2016) points out that eurodollar deposits have been shrinking because of the reform of money market mutual funds, described in Section VII, which forces foreign banks to lengthen the average term of their unsecured borrowing and reduces opportunities for arbitrage in the eurodollar market.

<sup>7</sup>See <https://apps.newyorkfed.org/markets/autorates/obfr>.

<sup>8</sup>Cipriani and Gouny (2015) describe the wholesale nature of the eurodollar market and the tight concentration of transaction rates on a given day, indicating a relatively competitive market.

<sup>9</sup>The results described in Ashcraft and Duffie (2007) are supported by logit-based estimates tabulated in Duffie (2012), Chapter 2.

<sup>10</sup>See, for example, Weitzman (1979).

<sup>11</sup>The Diamond (1971) Paradox implies that with  $\mu = 0$ , banks extract all rents from depositors, offering monopoly deposit rates.

<sup>12</sup>This requires only an easy scalar change in quantity of cash invested per bank, in the market-clearing conditions determining  $g$  and  $h$ .

<sup>13</sup>The mean of the deposit rates across all investors is not the mean of  $F_i$ , but instead reflects the fact that fast investors receive the rate  $\hat{r}^* = \max(r_1, \dots, r_N)$ .

<sup>14</sup>Pozsar (2016b) speculated that the Fed may offer these reverse repos to foreign central banks in a manner designed to promote pass-through of rates into the T-bill market. Potter (2016), of the Federal Reserve Bank of New York, stated the Fed does not use the foreign pool as a means for implementing monetary policy.

<sup>15</sup>See <http://www.federalreserve.gov/newsevents/press/monetary/20140917c.htm>.

<sup>16</sup>We cited Hannan and Berger (1991); Neumark and Sharpe (1992); Diebold and Sharpe (1990); Craig and Dinger (2011); Yankov (2014); Driscoll and Judson (2013); and Drechsler, Savov and Schnabl (2016).

<sup>17</sup>Two expectational flaws in our modeling of the effect of depositor attention deficits can be treated as follows. First, even if slow investors are not paying attention to news about changes in IOER, they could rationally anticipate on any given day that, with some probability  $p > 0$ , an increase in IOER has already occurred, causing an upward shift in the value of search to  $r_{F1} - c$ . This moves the lower support point for the distribution of  $F_1$  up to  $\hat{r} = (1 - p)r_{F0} + pr_{F1} - c$ . By replacing  $\underline{r}$  0 in (9) with  $\hat{r}$ , we can re-calculate the equilibrium offered rate distribution  $F_1$ . The equilibrium behavior is continuous in  $p$ , and for small  $p$  the resulting offered distribution  $F_1$  is close to that modeled above. The conceptual thrust of our conclusions about pass-through efficiency are thus preserved. The second expectational flaw is that the upper end of the support of  $F_1$  is above that for the lagged distribution  $F_0$ , implying that a slow investor will occasionally receive a rate offer that is higher than any offer supported by  $F_0$ . In this event, the slow investor thus immediately learns of the change in IOER, and becomes aware that the offer distribution of other banks is actually  $F_1$ , not  $F_0$ . (In the extended version of the model just described, the slow investor updates from the unconditional distribution  $pF_0 + (1 - p)F_1$  to the conditional distribution  $F_1$ .) Upon receiving such a high deposit rate offer  $r$ , the slow investor would only wish to continue comparison shopping if  $r < r_{F1} - c$ . For a small-enough adjustment in IOER, this will never happen in our static model, and equilibrium behavior is unaffected by this updating. In a dynamic model, this learning effect could be used as the basis for an update rule for the offered distribution  $F_i$  which would lead to a gradual response over time toward the new stationary offered rate distribution, interrupted by the next change in IOER, and so on. The impact of full Bayesian updating would be more complicated to model.

<sup>18</sup>See <http://www.federalreserve.gov/monetarypolicy/files/fomcminutes20140618.pdf>.

<sup>19</sup>Ruane (2015) discusses this effect, and also the costs associated with NSF of “operational complexity.”

<sup>20</sup>The bank subsidiaries of these holding companies must meet a 6 percent minimum leverage ratio.

<sup>21</sup>The analysis here is similar to that shown in Duffie (2016).

<sup>22</sup>For details, see Garbade (2006).

<sup>23</sup>See the figure at the bottom of page 22 of Ruane (2015).

<sup>24</sup>See, for example, Ruane (2015).

<sup>25</sup>Bech and Keister (2013) develop a Walrasian model of monetary policy implementation, showing that the LCR increases the steepness of the short-term yield curve, essentially because the LCR constraint forces banks to demand more borrowing at terms longer than 30 days relative to borrowing at terms under 30 days.

<sup>26</sup>Rezende, Styczynski and Vojtech (2016) provides evidence that beginning in October 2014 banks that would become subject to LCR in 2015 (in a graduated manner over time) tendered more aggressively in the Fed's term deposit facility than banks that would become subject only to the "modified" LCR, a weaker requirement. They also show that, beginning in 2013, the former type of bank increased HQLA holdings more than the latter type of bank. Beginning in October 2014, the term facility included an early withdrawal feature that allows the term deposits to count toward the LCR. The authors view this as evidence that the banks subject to LCR were responding to a potentially binding LCR constraint. They do not provide evidence on the shadow price of the implied constraint, that is, something akin to  $r_L - \phi$ . The Fed's term deposit facility is offered at rates set by the Fed, typically a few basis points above IOER.

<sup>27</sup>See Ken Brown, "A \$500 Billion Stampede in Money Markets Even Before New Rules Hit," *The Wall Street Journal*, Aug. 3, 2016, at <http://www.wsj.com/articles/a-500-billion-stampede-in-money-markets-even-before-new-rules-hit-1470248418>.

<sup>28</sup>Before the rule change, CNAV prime funds were treated as "quasi-deposits," which inefficiently depressed effective credit spreads in private-market paper. In this sense, the new rule can be viewed in part as the elimination of a regulatory distortion in money market rates.

<sup>29</sup>See Pozsar and Smith (2016) for details on the resulting new term U.S. dollar unsecured funding requirements of individual banks, country by country and the likely impacts on three-month LIBOR.

<sup>30</sup>For institutional reasons explained by Bech and Klee (2011), Garratt, Martin, McAndrews and Nosal (2015) and Pozsar (2016a), among others, FFER is essentially the average rate at which GSEs lend their Federal Reserve deposits (on which they do not earn interest) to foreign banks, in a submarket closer to the fringe than the center of the interbank market.

<sup>31</sup>The minutes of the FOMC of Dec. 15-16, 2015, state "the possibility that the Federal Reserve, in cooperation with the Office of Financial Research, might publish a reference rate for overnight transactions collateralized by Treasury securities." See <https://www.federalreserve.gov/monetarypolicy/fomcminutes20151216.htm>. See, also, Powell (2016), at <https://www.federalreserve.gov/newsevents/speech/powell20160621a.htm>

and Alternative Reference Rates Committee (2016), where the Committee writes about its proposed new overnight benchmarks: "After extensive discussion, the ARRC has preliminarily narrowed this list to two rates that it considers to be the strongest potential alternatives, the OBFR and some form of overnight Treasury GC repo rate."

<sup>32</sup>The proposal, subject to approval, would have some large institutional cash investors such as money funds provide a committed line of collateralized cash lending to a "capped, committed liquidity facility" (CCLF), for a period of up to several days. See Smith (2016).

<sup>33</sup>Under pressure from the Federal Reserve Bank of New York, the TPR clearing banks, BNY Mellon and JPMorgan Chase, have largely eliminated their intraday exposure to dealers, which had been a major concern during the financial crisis. These and other tri-party infrastructure reforms are described by Copeland, Martin and Walker (2010) and Ruane (2015). As explained by Begalle, Martin, McAndrews and McLaughlin (2013), however, there remains important "fire sale" risk associated with the potential failure of a major dealer, whose collateral might need to be quickly sold, including substantial amounts of relatively illiquid collateral. Furthermore, the current tri-party settlement medium is the commercial bank deposits of the clearing banks, contrary to IOSCO (2012) principles.

<sup>34</sup>We learned of this spread in a private conversation with one of the major dealers. Smith (2016) mentions that the cross-bank GCF spread at one point reached 30 basis points, but such a wide spread must have been very short lived.

<sup>35</sup>According to comments from a market participant, JPMorgan Chase will continue to handle some other forms of TPR clearing.

<sup>36</sup>See <https://fred.stlouisfed.org/categories/121>.

<sup>37</sup>See [http://dtcc.com/data/GCF\\_Index\\_Graph.xlsx](http://dtcc.com/data/GCF_Index_Graph.xlsx).

<sup>38</sup>See [https://www.newyorkfed.org/banking/tpr\\_infr\\_reform\\_data.html](https://www.newyorkfed.org/banking/tpr_infr_reform_data.html).

<sup>39</sup>See <https://repoindex.bnymellon.com/repoindex/>.

<sup>40</sup>See <https://fred.stlouisfed.org/series/USDONTD156N>.

<sup>41</sup>See <http://www.treasurydirect.gov/govt/reports/pd/mspd/mspd.htm>.

<sup>42</sup>Previously, in Chart 1, we used a 120-day rolling averages, given the extreme fluctuations that occur during the financial crisis if this further adjustment  $u(t) - s(t)$  to unsecured rates is not applied.

<sup>43</sup>To close the model in a general equilibrium, we require that  $(1 - \mu)w + \mu W = R + \frac{s}{1+g} + \frac{L}{1+r_l}$  (total depositor wealth equals total economywide assets) and  $R > (1 - \mu)w$  (a positive quantity of HQLA back the fast investors' deposits).

<sup>44</sup>In the equilibria we construct,  $g < \varphi$ , so that banks will never choose to hold T-bills to satisfy their HQLA demand. This is why we write the total supply of HQLA as  $R$  rather than including the T-bill supply of  $S$ .

## References

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