Money Market Funds and the Pricing of Near-Money Assets*

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Abstract

US money market funds (MMFs) play an important role in short-term markets as large investors of Treasury bills (T-bills) and repurchase agreements (repos). We build a theoretical model in which MMFs strategically interact with banks and each other. These interactions generate interdependencies between repo and T-bill markets, affecting the pricing of these near-money assets. Consistent with the model's predictions, we empirically show that when MMFs allocate more cash to the T-bill market, T-bill rates fall, and the liquidity premium on T-bills rises. To establish causality, we devise instrumental variables guided by our theory. Using a granular holding-level dataset to examine the channels, we show that MMFs internalize their price impact in the T-bill market when they set repo rates and tilt their portfolios towards repos with the Federal Reserve when Treasury market liquidity is low. Our results have implications for the transmission of monetary policy, benchmark rates, and government debt issuance.

Keywords: T-bills, repo, money market funds, near-money assets, liquidity
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1 Introduction

US Treasury bills (T-bills) and repurchase agreements (repos) are among the most important financial instruments of global finance. T-bills are safe, liquid, and considered the global risk-free asset (Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood, Hanson and Stein, 2015; Nagel, 2016). Repos are instrumental for banks and other financial institutions to raise short-term capital and manage liquidity needs (CGFS, 2017). The importance of repos is set to increase further as repo-based reference rates replace LIBOR in derivatives markets. Through the reverse repo (RRP) facility, repos issued by the Federal Reserve also constitute a critical monetary policy instrument (Afonso et al., 2022a).[1]

We show that strategic interactions of US money market funds (MMFs), which are key investors in T-bills and repos, with banks and each other significantly impact the pricing of the world's safest and most liquid assets. We first show theoretically that when MMFs charge higher rates in the repo market, demand for repos decreases, leaving MMFs with more "residual cash" available to invest in the T-bill market. Due to MMFs' price impact in the T-bill market, higher rates in the repo market cause T-bill rates to fall. The existence of the RRP alleviates these effects but does not eliminate them. We then devise instrumental variables guided by our model to establish empirically that MMFs' portfolio allocations have the predicted effects and that they are economically significant. We also use a granular holding-level dataset to examine the channels outlined in the model. We further show that MMFs internalize their price impact in the T-bill market when they set repo rates and tilt their portfolios towards repos with the Federal Reserve when Treasury market liquidity is low.

Our results have implications for the transmission of conventional and unconventional monetary policy, repo-based benchmark rates' robustness, and government debt issuance. First, MMFs typically receive inflows when the federal funds rate increases (e.g. Duffie and Krishnamurthy, 2016; Drechsler, Savov and Schnabl, 2017; Xiao, 2020). At the same time, to the extent that inflows increase their T-bill demand, they put downward pressure on T-bill rates due to MMFs'

[1] For collateral providers (banks and the Federal Reserve), these transactions are called repos. For cash lenders (MMFs), they are called reverse repos. For brevity, we refer to these transactions as repos throughout the paper.

price impact, weakening the transmission mechanism of monetary policy. However, a larger central bank balance sheet with greater availability of the RRP facility can partly offset this channel. Second, as the transition from credit-sensitive (LIBOR) to risk-free repo-based benchmark rates (SOFR) is underway (Huang and Todorov, 2022), our results imply that the market structure and liquidity conditions in the repo and Treasury markets impact benchmark rates and hence have spillover effects to other markets.[2] Third, as the price impact of MMFs arises due to supply-demand imbalances in the T-bill market, targeted government debt issuance could alleviate these imbalances, improving liquidity and increasing government revenues.

Our analysis begins with a model of strategic interactions of MMFs with banks in the repo market and each other in the T-bill market. Funds optimally set repo rates with banks and allocate their funds between repos with banks, T-bills, and repos with the Federal Reserve. Consistent with the data, the model features market concentration, and large funds simultaneously account for a significant share in the repo and T-bill markets. These patterns create the crucial trade-off between MMFs' *market power* in the repo market and their *price impact* in the T-bill market.[3] All else equal, funds with greater market power charge higher rates, so banks demand fewer repos. As a result, MMFs allocate more of their cash to T-bills, thereby putting downward pressure on T-bill rates due to their price impact.

Our model provides insights into why most MMFs invest both in T-bills and the RRP facility, two close substitutes for cash management purposes. The RRP facility provides MMFs, which are ineligible to receive interest on reserve balances held at the Federal Reserve, with a risk-free overnight investment option. The rate is set administratively by the Federal Reserve and is fixed, so MMFs have no price impact.[4] This leads to an interesting problem for the allocation between T-bills and RRP. Without any price impact in the T-bill market, MMFs would allocate all their

[2]As a case in point, when MMFs contributed to ructions in repo markets in September 2019, this has led to significant moves in the SOFR (e.g. Avalos, Ehlers and Eren, 2019; Afonso, Cipriani, Copeland, Kovner, La Spada and Martin, 2020; Correa, Du and Liao, 2020; d'Avernas and Vandeweyer, 2020; Copeland, Duffie and Yang, 2021).

[3]Several papers have shown that banks also have market power in the repo market (see, e.g. Aldasoro, Ehlers and Eren, 2022; Huber, 2022). We account for this possibility in our model, as both MMFs and banks' relative market power matter for driving the results. We fix banks' power to focus on the trade-offs MMFs face. In our empirical setup, we show that MMF market power affects repo rates even when we control for bank*time fixed effects, which absorb unobservable time-varying bank characteristics, including bank market power.

[4]Even though there are counterparty limits, all MMFs are well below this limit as of the end of 2022.

residual cash entirely in T-bills or the RRP, depending on which instrument offers a higher rate. However, in the data, funds typically choose an interior solution for their allocation between T-bills and the RRP. Our model generates this interior solution by assuming a non-monetary cost associated with investing in the RRP facility. Hence funds trade off this cost and their price impact in the T-bill market to find an optimal allocation. A consequence is that the RRP alleviates but does not eliminate MMFs' price impact considerations. Moreover, the model predicts that MMFs tilt their asset allocation more towards the RRP when the Treasury market is illiquid, that is when their price impact is greater.

We find empirical evidence consistent with our model's predictions. We first demonstrate that MMFs' residual cash share has a significant negative correlation with the T-bill-RRP spread in time series regressions at the monthly level. By using the spread of T-bill rates over the RRP rate, our regressions account for the impact of aggregate macroeconomic conditions, as they are reflected in the interest rate on the RRP set by the Federal Reserve. Moreover, we find that adding the residual cash share to standard specifications in the literature that explain the spread improves the explanatory power markedly. Second, we find that an increase in the residual cash share is associated with a significant increase in the liquidity premium of T-bills.

Our estimated coefficients are economically significant. The partial impact of a standard deviation increase in the average MMF share of residual cash from repo lending on the spread between the 1-month T-bill rate and the RRP rate is equivalent to the partial effect of around one percentage point increase in the federal funds rate, or around a third of a percent increase in the T-bill supply normalized by GDP. Similarly, the partial impact of a standard deviation increase in the average MMF share of residual cash from repo lending on the spread between the 1-month GC repo rate and 1-month T-bill rate is equivalent to the partial effect of an around one percentage point rise in the federal funds rate, or an around one-fifth of a percent rise in the T-bill supply normalized by GDP.

The residual cash share variable is an equilibrium outcome, so regressing rates on quantities is subject to endogeneity concerns. For example, changes in the T-bill rate could affect the residual cash share. To isolate the exogenous variation in the residual cash share and establish a causal effect of MMFs' portfolio allocation on the various outcome variables, we construct an instrumental variable guided by our theory. In the model, higher market concentration in the repo market leads to higher repo rates, which lowers the aggregate bank demand for repos – as we observe in the microdata. As a consequence, MMFs have more residual cash to invest in the T-bill market, independent of conditions in the T-bill market. Our main instrumental variable is hence the Herfindahl-Hirschman Index (HHI) of market concentration in the bank repo market. It is constructed from funds' market shares in the repo market.

We follow two approaches to address the remaining concerns with our instrumental variable strategy. One concern is that banks' demand for repos could jointly affect the HHI and T-bill markets, violating the exclusion restriction. To isolate variation in the HHI that is not driven by banks' demand, we thus take out each bank's demand at a given time by first regressing the size of each individual contract on bank-time fixed effects. We then reconstruct the HHI from the residuals. Second, to address the concern that changes in the HHI mostly reflect the 2016 US MMF reform that drastically increased concentration in the repo market (see Aldasoro, Ehlers and Eren (2022)), we show that our results also hold when we focus only on the post-reform period.

After establishing the aggregate impact of MMFs in the T-bill market, we provide evidence for the underlying channels with a detailed dataset of US MMFs' portfolio holdings at individual holding levels. The data, obtained from MMFs' regulatory filings, cover the universe of US MMF funds between February 2011 to October 2022 and provide detailed information on contract characteristics for each holding. We construct counterparts of key model variables in the data for funds' market shares in the repo and T-bill markets and their residual cash, overall market concentration in the repo market, and Treasury market liquidity.

We find evidence for the predictions of the model on the market power vs. price impact trade-off and the impact of liquidity conditions in the Treasury market on MMF portfolio allocations. First, funds' market share (i.e., market power) in the repo market positively affects repo rates between MMFs and banks. In contrast, funds' market share in the T-bill market affects repo rates negatively. This result is consistent with the interpretation that MMFs internalize their price impact in the T-bill market when they set repo rates. Due to the granular nature of our data, we can control for a battery of time-varying fixed effects to rule out alternative explanations arising from potential differences in the time-varying unobservable bank, instrument, or fund-type characteristics. Second, we show that funds allocate more of their residual cash to the RRP if Treasury market liquidity is low, even when controlling for fund-fixed effects and several time-varying characteristics through fixed effects (which absorb the impact of movements in the interest rates of T-bills and the RRP facility).

Related literature. Our paper contributes to a large literature that studies the relationship between the supply and liquidity of government debt, short-term rates, and money market conditions (e.g. Duffee, 1996; Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood, Hanson and Stein, 2015; Nagel, 2016; d'Avernas and Vandeweyer, 2021).[5] The importance of liquidity conditions in the Treasury market became particularly visible during the Covid-19 crisis (e.g. Duffie, 2020; Schrimpf, Shin and Sushko, 2020; Vissing-Jorgensen, 2021; Barth and Kahn, 2021; Eren and Wooldridge, 2021; He, Nagel and Song, 2022). Our paper contributes to this literature by highlighting the key role MMFs play in Treasury markets and how market frictions in repo markets and liquidity conditions in T-bill markets can affect key interest rates and spreads in the macroeconomy through MMFs' portfolio allocations, with important consequences for the global economy.

Our paper also provides new insights into the role of MMFs in short-term money markets and monetary policy transmission. Several studies have documented the key role of MMFs in the repo and other short-term money markets, including during crisis episodes.[6] Other studies show that MMFs have an important role in the transmission of monetary policy through banks and non-bank lenders (e.g. Duffie and Krishnamurthy, 2016; Drechsler, Savov and Schnabl, 2017; Xiao, 2020). Our contribution is to show the importance of jointly accounting for optimal price setting and asset allocations between T-bills, RRP, and repos in studying these issues. We further provide a

[5]See also Amihud and Mendelson (1991); Longstaff (2004); Goldreich, Hanke and Nath (2005); Greenwood and Vayanos (2014); Krishnamurthy and Vissing-Jorgensen (2015); Sunderam (2015); Nagel (2016); Lenel (2017); Lenel, Piazzesi and Schneider (2019); Li, Ma and Zhao (2019); Klingler and Sundaresan (2020); Jiang, Krishnamurthy and Lustig (2021); Engel and Wu (2021); Krishnamurthy and Li (2022); Du, Hébert and Li (2022).

[6]See Kacperczyk and Schnabl (2013); Chernenko and Sunderam (2014); Krishnamurthy, Nagel and Orlov (2014); Copeland, Martin and Walker (2014); Schmidt, Timmermann and Wermers (2016); Han and Nikolaou (2016); Eren, Schrimpf and Sushko (2020a,b); Hu, Pan and Wang (2021); Cipriani and La Spada (2021); Li (2021); Aldasoro, Ehlers and Eren (2022); Anderson, Du and Schlusche (2022); Huber (2022); Afonso, Cipriani and La Spada (2022b).

novel channel through which frictions specific to MMFs can weaken monetary policy transmission through funds' price impact in the T-bill market and how the RRP facility can partially offset this effect.

2 Facts on MMFs, T-bills, repos, and the RRP facility

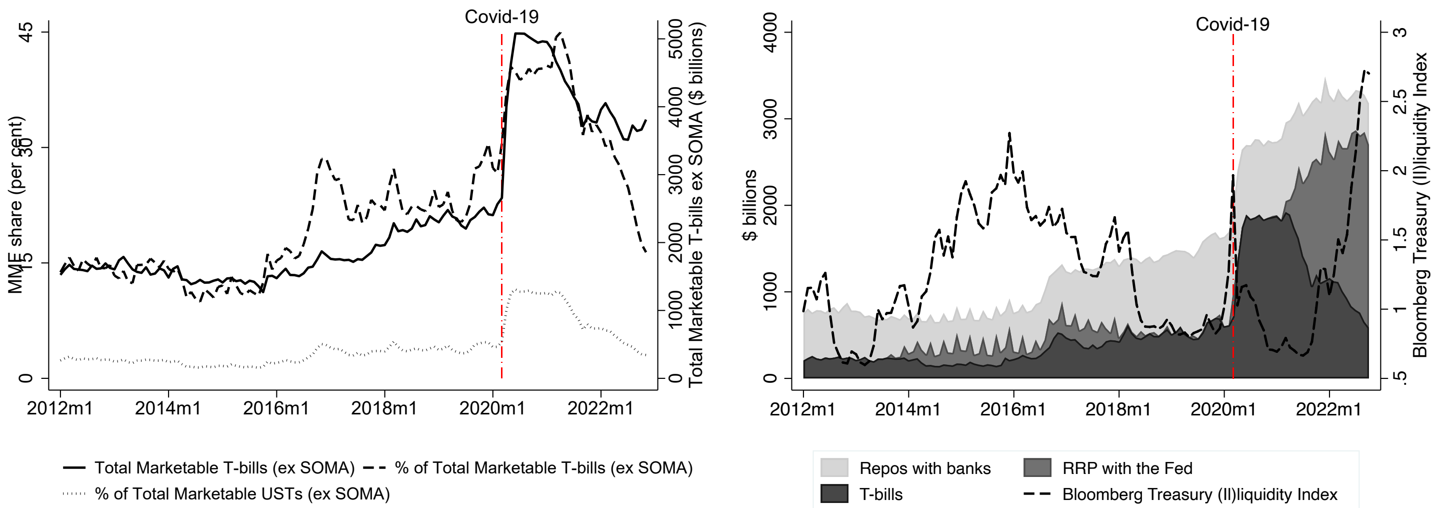
This section presents a number of stylized facts. It provides institutional background on MMFs, T-bills, repos, and the RRP facility, which form the basis for our model and empirical analysis.

Money Market Funds. US MMFs are short-term investment vehicles with a total AUM of around $5 trillion as of end-2022, which is roughly equal to 20% of US GDP or total US commercial bank assets. Investments in near-money assets, T-bills, RRP, and repos amount to around $3 trillion. They issue money market shares to investors and invest proceeds into short-term investments.

There are three major types of funds that we focus on in our study. *Treasury funds* are only allowed by regulation to invest in T-bills and repos backed by Treasury securities. *Government funds* are allowed to invest in a broader set of instruments, such as agency debt and repos backed by agency collateral, in addition to what the Treasury funds can invest in. *Prime funds* can in addition invest in unsecured instruments, such as commercial paper and certificates of deposits. Since we are interested in the pricing of near-money assets, we focus on MMF investments into T-bills and repos with banks and the Federal Reserve.

Fact 1: MMFs hold a substantial share of T-bills. T-bills are considered one of the world's safest and most liquid assets. MMFs have been significant players in T-bill markets throughout our sample period (since 2011) and their share of holdings of total marketable T-bills increased markedly from 2016 onward. During the Covid-19 crisis, the share of MMF holdings of total marketable T-bills (excluding those held by the Federal Reserve at the SOMA portfolio) rose to more than 45%. Their holdings in the entire Treasury market (again excluding SOMA portfolio holdings) also rose to around 11% (see Figure 1(a)). In 2022, however, their share in the T-bill market declined as they substituted into the RRP facility of the Federal Reserve, one of the facts for which we set out to explain.[7]

Figure 1: MMFs' role in the T-bill and repo markets (with banks and RRP)



(a) MMFs' comprise a substantial share of the T-bill market

(b) MMF portfolio allocation between T-bills, repo, and RRP varies over time

Notes: In Panel 1(a), the solid line is the time series of the total marketable T-bills excluding those held at the SOMA portfolio. The dashed line shows the MMF share of holdings of the total represented in the solid line. The dotted line shows the MMF share of total holdings of all US Treasuries, excluding those held in the SOMA portfolio. In Panel 1(b), the darkest area shows the total T-bill holdings of MMFs, the medium dark area shows the total investments in the RRP facility, and the lightest area shows the total repos with banks. The dashed line shows the Bloomberg Liquidity Index, measured by the deviations from a fair value model across the yield curve. Higher values correspond to lower liquidity. Source: Crane Data, US Treasury, Bloomberg

Fact 2: Investments of MMFs between T-bills, RRP, and repos vary over time Repos with banks have been roughly stable since 2012.[8] During the first months of the Covid-19 crisis, MMF holdings of T-bills increased to more than \$1 trillion. Since the end of 2021, as T-bill issuance has declined and liquidity conditions in the Treasury market deteriorated (see the dashed line in Figure 1(b))), their holdings of T-bills declined, while their holdings in the RRP skyrocketed to more than \$2 trillion (see Figure 1(a).[9]

[7] The RRP facility was introduced as a supplementary policy tool to help control the federal funds rate and keep it in the target range set by the FOMC. It provides MMFs, which are ineligible to receive interest on reserve balances held at the Federal Reserve, with a risk-free overnight investment option.

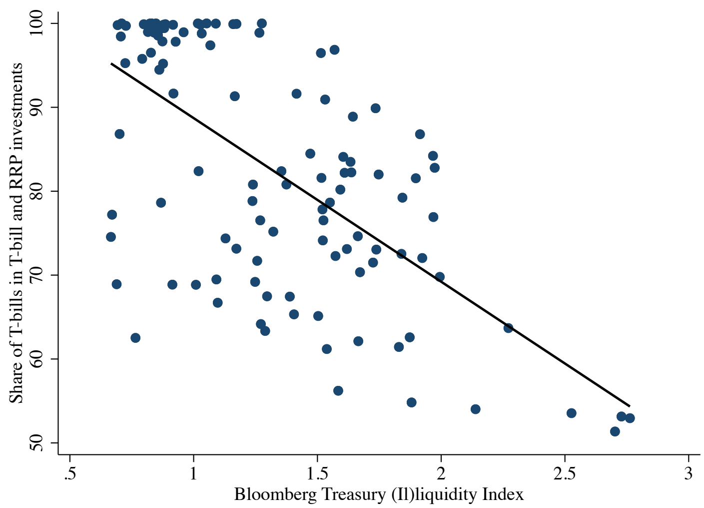
[8] Before the Covid-19 crisis, at quarter-ends and regulatory reporting periods, some banks withdrew from repo markets and the MMFs would instead invest in the RRP facility (Aldasoro, Ehlers and Eren, 2022).

[9] We use the Bloomberg index for Treasury market liquidity. Higher values of the index correspond to greater

Fact 3: Most MMFs invest both in T-bills and the RRP. Moreover, the portfolio allocation between T-bills and RRP is highly correlated with Treasury market liquidity. Despite the high degree of complementarity between T-bills and RRP, MMFs typically hold an interior mix between the two assets. Furthermore, we document in Figure 2(b) that the average share of assets allocated to T-bills versus the RRP correlates negatively with the liquidity of the Treasury market (measured by the Bloomberg liquidity index: higher values indicate lower liquidity).

Figure 2: Correlation of market shares in repo and T-bill markets, and MMF portfolio allocation

(a) Market shares of funds in repos with banks and T-bills are positively correlated, giving rise to a trade-off between market power and price impact.



(b) Liquidity conditions correlate with funds' asset allocation between T-bills and RRP

Note: In Panel 2(a), we plot the average market share over time of each individual fund in the repo market on the y-axis against the average market share in the T-bill market. In Panel 2(b), we plot the share of investments in T-bills in total T-bill and RRP investments on the y-axis against the Bloomberg Liquidity Index on the x-axis. For the Bloomberg Liquidity Index, higher values correspond to lower liquidity in the Treasury market. Source: Crane Data, Bloomberg.

Fact 4: The repo market is concentrated, and repo rates, on average, exceed T-bill and RRP rates. Measured by the Herfindahl-Hirschmann Index (HHI), holdings of MMFs of both T-bills and repos with banks are much more concentrated than if each fund held an equal share in

illiquidity (or lower liquidity). It measures deviations of yields from a fair-value model. It is constructed from the entire yield curve and is a standard gauge of government bond market illiquidity.

these markets.[10] Market concentration leads to imperfect competition, which is well-documented in the literature. The concentration of funds in the repo market increased in response to the 2016 US MMF reform (see, e.g. Han and Nikolaou, 2016; Hu, Pan and Wang, 2021; Aldasoro, Ehlers and Eren, 2022). Partly a reflection of their market power in the repo market, MMFs typically obtain a higher interest rate by lending in the repo market compared to investing in T-bills or the RRP facility. Indeed, on average return over the sample period for funds is the highest from repo lending to banks, followed by the average return on T-bills and the average return on the RRP facility. We document summary statistics about market concentration and monthly average interest rates in Table 1.

Table 1: Summary statistics for various rates and market concentration

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
repo rate	110	88.94	92.15	7.16	380.3	39.73
Tbill rate (1M)	110	75.24	92.4	1	387	23
RRP rate	110	71.1	87	0	373	25
HHI bank repo	110	281.25	69.46	160.12	384.69	300.48
HHI (pre-reform)	36	192.93	33.15	160.12	332.34	185.33
HHI (post-reform)	74	324.22	30.97	273.1	384.69	320.8

Note: The table reports the summary statistics of all variables across months. To make the summary statistics comparable, in this table, we only report the statistics since the introduction of the RRP facility in October 2013 until November 2022 (end of our sample period). *repo rate*, *Tbill rate* $(1M)$ and *RRP rate* are in basis points. *repo rate* is constructed from Crane Data. *Tbill rate* $(1M)$ and *RRP rate* are monthly averages of daily data. We use the 1-month T-bill and overnight RRP rates to calculate the $Tbill - RRP$ spread. HHI *bank repo* measures the HHI of funds in the repo market and is between 0 and 10,000 (constructed by summing the squared market share of each fund in the repo market). $HHI\ (pre-reform)$ refers to HHI *bank repo* before the implementation of the US MMF reform in October 2016. $HHI\ (post-reform)$ refers to HHI *bank repo* after the implementation of the US MMF reform in October 2016 (October 2016 is included in the $HHI\ (post-reform)$). *Data sources:* Crane Data, FRED

Fact 5: Larger funds have a higher market share both in the repo market with banks and in the T-bill market. We document this pattern in Figure 2(a). In the presence of

[10] With 462 unique funds in our dataset, an equal share of each fund would lead to an HHI of 21, which is more than ten times lower than the average HHI over the sample period.

frictions, being a large player in the repo market potentially increases its market power. At the same time, being large in the T-bill market might also imply a price impact in this market. This trade-off is a key consideration in our model.

3 A model of MMFs and near-money assets

Motivated by the facts presented in the previous section, we model how MMFs set repo rates with banks and allocate their funds between repos with banks, T-bills, and the RRP facility. The model accounts for strategic interactions between MMFs and banks as well as between MMFs. MMFs strategically interact with banks in the repo market and have market power. Any residual funds MMFs do not lend to banks in equilibrium; they split between T-bills and the RRP. As large players, they can have a price impact on the T-bill market.

The key insight of the model is that market power in the repo market and liquidity conditions in the T-bill market affect equilibrium outcomes in both markets. This trade-off can be summarised by a simple example. Suppose a large fund can only invest in repos with banks or T-bills. Market power in the repo market means it can increase the rates it charges for repos.[11] As higher rates reduce demand, the fund has more residual cash left over from repo lending to invest in the T-bill market. Due to its price impact, the more it invests in T-bills, the more it put downward pressure on T-bill rates – reducing its return. If the fund is large in both markets, it will internalize this price impact and set rates in repos accordingly.

3.1 Model setup: The repo market

There are B banks indexed by $b = 1, \cdots, B$ and F funds indexed by $f = 1, \cdots, F$. Each fund f is characterized by its size, w_f.

In the repo market, fund f offers a rate $r_f(b)$ to bank b. As is standard in the literature on

[11] Empirically, it is the case that MMFs and banks both possess varying degrees of bargaining power. Our setup acknowledges and proxies for bank market power. Therefore, the MMF market power can be interpreted as the relative power of the MMFs.

industrial organization, we assume that bank b chooses to borrow from fund f with probability[12]

$$\pi_f(r_f(b);b) \;=\; \frac{r_f(b)^{-\alpha_b} w_f}{\sum_{\phi=1}^{F} r_\phi(b)^{-\alpha_b} w_\phi},$$

Here, α_b is the bank-specific sensitivity of the demand for loans for the offered rate $r_f(b)$, and $\phi = 1, \cdots, F$ is used to index the funds. We use this sensitivity as a proxy for bank market power in negotiations with funds. The dependence on size w is a reduced form model of market power: bigger funds have a higher chance of lending to a given bank.

We start by describing and solving the rate choice problem of a bank. We assume that bank b has access to a decreasing-returns-to-scale technology that returns $\ell^{1-1/\xi} R_*$ for an investment amount of ℓ. Thus, the objective of a bank b borrowing amount ℓ at a rate $r_f(b)$ is given by

$$\max_{\ell} (\ell^{1-1/\xi} R_* - \ell r_f(b))\,,$$

implying the following demand curve for repos:

$$\ell(r_f(b)) \;=\; \underbrace{r_f^{-\xi} R_*^{\xi}}_{downward\ sloping\ demand\ for\ repos} \tag{1}$$

The demand for repos in equation (1) limits the ability of funds to extract rents from banks and exploit arbitrage opportunities between the T-bill and the repo market.[13]

We assume that each fund f has an outside option to invest any available cash at a rate of ρ. For now, we treat this rate as exogenous but endogenize it in the next section. The objective of fund f is thus to maximize the excess returns (markups) from lending to bank b over $r_f(b)$:

$$\begin{aligned} \Pi \;=\; & \underbrace{\pi_f(r_f(b);b)}_{success\ probability} \times \underbrace{\ell(r_f(b))}_{banks'\ demand} \times \underbrace{(r_f(b)-\rho)}_{markup} \\ =\; & \frac{w_f r_f(b)^{-\alpha_b}}{\sum_\phi r_\phi(b)^{-\alpha_b} w_\phi} R_*^{\xi} (r_f(b)^{1-\xi} - \rho r_f(b)^{-\xi})\,. \end{aligned} \tag{2}$$

[12]It is straightforward to micro-found this demand with random preference shocks.

[13]In some of our empirical tests, we allow the parameter ξ to be bank-specific, allowing us to study the effect of the joint variation in market power across funds and banks.

Funds behave strategically because, through the success probability term $\pi_f(r_f(b); b)$, they are in direct competition with other funds. Consider first the simpler case where the funds' market power is negligible (that is, w_f is sufficiently small). In this case, the fund ignores the competition with other funds in the repo market, and the first-order conditions for equation (2) take the form

$$(1-\xi-\alpha_b) r_f(b)^{-\xi-\alpha_b} + (\xi+\alpha_b)\rho r_f(b)^{-\xi-\alpha_b-1} = 0\,,$$

implying a standard monopolist solution

$$r_*(b) \;=\; \rho\frac{\xi+\alpha_b}{\xi+\alpha_b-1} \;=\; \rho \;+\; \underbrace{\rho\frac{1}{\xi+\alpha_b-1}}_{markup}\,. \tag{3}$$

The fund's problem is significantly more complex in the presence of market power. Define

$$\Gamma_*(b) \;=\; \sum_{\phi} r_\phi(b)^{-\alpha_b} w_\phi\,.$$

This is a key quantity in our analysis, capturing the degree of competition in the repo market. The following result follows by direct calculation:

Lemma 3.1 (Optimal rates with imperfect competition) *The optimal rate satisfies*

$$r_f(b) \;=\; r_*(b) \;+\; \underbrace{\frac{1}{\alpha_b+\xi-1}\frac{\alpha_b r_f(b)^{-\alpha_b} w_f (r_f(b)-\rho)}{\Gamma_*(b)}}_{additional\ markup}\,. \tag{4}$$

In general, equation (4) is a complex, non-linear equation defining the equilibrium relationship between rates charged by different funds (to different banks). However, when the number of funds is large and the size of each fund is small, it is possible to derive an approximate, closed-form solution for the repo market equilibrium. The following is true.

Proposition 3.2 (Equilibrium in the repo market) *Suppose that $w_f = w_f^*/F$, where w_f^* are* *uniformly bounded. For simplicity, we normalize* $\sum_f w_f^* = F$.[14] *Define*

$$H(W) \ = \ F^{-1} \sum_f (w_f^*)^2$$

to be the Herfindahl index of the fund size distribution. Then, for large F*, the equilibrium repo rate* $r_f(b)$ *depends positively on* $H(W)$*.*

Proposition 3.2 shows how imperfect competition in the repo market makes it optimal for funds to charge additional markups, over and beyond the one in equation (3). The size of these additional markups increases in the concentration in the repo market, captured by the Herfindahl Index $H(W)$.

3.2 T-bill market

We now introduce a simple model for rate determination in the T-bill market. The supply of treasuries is fixed by an exogenous number S. We assume that the T-bill market is populated by two types of agents: Liquidity providers and MMFs.

We model liquidity providers through an exogenous demand curve,

$$D(\rho) = a + \lambda \rho \,, \tag{5}$$

where ρ denotes the rate on T-bills. The behavior of MMFs is more subtle. We assume that a fund f has *residual cash,* Δ_f, that must be invested either in T-bills or in the RRP. The RRP rate is fixed at an exogenous ρ_*. Intuitively, we would expect that the demand D_f^T of fund f for Treasuries satisfies $D_f^T = \mathbf{1}_{\rho > \rho_*} \Delta_f$. That is, the fund would invest everything into Treasuries if the rate is above ρ_*, and invest all residual cash into RRP when $\rho_* > \rho$. However, this is not what we observe in the data. As Figure 1(b) shows, MMFs buy non-trivial amounts of treasuries even when ρ is significantly below ρ_*, suggesting that some frictions prevent MMFs from selecting this corner solution. One may then ask: Are MMFs responding *elastically* to changes in the T-bill rate? In the

[14]E.g., the most competitive case corresponds to an equal distribution of size across funds, $w_f^* = 1/F$, with $H(W) = 1/F$, the lowest possible value.

data, it is indeed the case: When ρ is above ρ_*, funds buy more T-bills. We model this price-elastic behavior by assuming demand curves

$$D_f^T(\rho) \;=\; (a_*(f) + \lambda_*(f)(\rho - \rho_*))\Delta_f \tag{6}$$

with some fund-specific coefficients $a_*(f),\ \lambda_*(f) > 0$. Funds with a higher $\lambda_*(f)$ are more elastic concerning T-bill rate changes and are, therefore, more aggressive in absorbing supply shocks and providing liquidity. Under the above assumptions, the T-bill rate is pinned down by the market-clearing condition

$$a + \lambda\rho \; + \sum_f (a_*(f) + \lambda_*(f)(\rho - \rho_*))\Delta_f \;=\; S\,. \tag{7}$$

Solving equation (7), we arrive at the equation

$$\hat{\rho} \;=\; \rho_* \;+\; \underbrace{\frac{S - a - \sum_f a_*(f)\Delta_f}{\lambda + \sum_f \lambda_*(f)\Delta_f}}_{demand-supply\ imbalance}, \tag{8}$$

showing explicitly how the demand by MMFs affects the equilibrium T-bill rate.

A related key question is: Do MMFs internalize their price impact in the T-bills market when they set rates in the repo market? Here, one could consider two layers of internalization: The effect of the T-bill price impact of a given fund f on (i) the fund's rate setting in the repo market; (ii) the rates set by other funds. We ignore the latter channel because it has lower-order effects and focuses on channel (i).

3.3 Strategic behavior across the two markets

We assume that each MMF starts with a deposit base d_f, which is split between lending to banks and investments into T-bills and the RRP. Thus, the residual cash – i.e., the amount of deposits not invested into repos with banks – is given by

$$\Delta_f \ = \ d_f - \underbrace{\sum_b (R_*/r_f(b))^{\xi} \frac{r_f(b)^{-\alpha_b} w_f}{\Gamma_*(b)}}_{repo\ lending\ given\ banks'\ demand\ curves} \ . \tag{9}$$

Equation (9) defines the key mechanism of our model: If a fund chooses higher rates $r_f(b)$, banks' demand for repos falls, leaving the fund with more residual cash. The fund is then forced to invest this cash into T-bills; if the T-bill market is illiquid, buying a lot of T-bills creates a price impact, making this investment less attractive. When optimizing profits, funds take this price impact into account.

Proposition 3.3 (Pass-through of repo rates into treasuries) *Suppose that F is large and $d_f = O(w_f)$, and that fund f takes the repo rates charged by other funds, $r_\phi, \phi \neq f$, as given. Then, the equilibrium T-bill rate responds to changes in funds' repo rate, $r_f(b)$, for any b. The sensitivity, $\frac{\partial \hat{\rho}}{\partial r_f(b)}$, is negative and its absolute value is larger for funds with bigger w_f and d_f.*

Proposition 3.3 shows how a strategic change in the repo rate, through its impact on the residual cash and the demand function of the fund for T-bills, affects the equilibrium T-bill rate $\hat{\rho}$. Funds rationally anticipate their price impact through $\frac{\partial \hat{\rho}}{\partial r_f(b)}$ and take it into account when setting the repo rate $r_f(b)$.

Having identified this pass-through coefficient, we can now write down the first-order condition of each fund concerning the rate $r_f(b)$ it charges to a particular bank. Solving these first-order conditions leads to the equilibrium link between the repo rates set by a fund and the T-bill rate, $\hat{\rho}$.

Proposition 3.4 (Equilibrium Repo Markups) *The optimal repo rate set by fund f for bank b is monotone increasing in the fund market power, as captured by w_f^*, and is monotone decreasing in the fund's residual cash.*

The intuition behind Proposition 3.4 is straightforward: Funds with more market power charge higher rates. However, funds with more residual cash strategically internalize their price impact on the T-bills. This makes it optimal for them to charge lower rates in the repo market so that they lend more; as a result, they have less residual cash and can place this cash at better terms in the T-bill market.

3.4 Equilibrium T-bill rate

In this section, for simplicity, we assume that all banks have the same elasticity coefficient: $\alpha_b = \alpha$ is independent of b.[15] In this case, absent market power, fund f charges the rate

$$r_*(f) \;=\; \frac{\alpha+\xi}{\alpha+\xi-1}\widetilde{\rho}_f^*$$

to all banks in the repo market, where

$$\widetilde{\rho}_f^* \;\equiv\; \Big((a_*(f)+\lambda_*(f)(\rho^*-\rho_*))(\rho^*-\rho_*) \;+\; \rho_*\Big)$$

is the effective rate earned by fund f on its residual cash, and where ρ^* is the frictionless equilibrium rate, given by

$$\hat{\rho}^* \;=\; \rho_* \;+\; (\lambda+\bar{\lambda})^{-1}\Big(\underbrace{S}_{supply} - \underbrace{\Big(a+\sum_f a_*(f)\Delta_f(0)\Big)}_{demand}\Big), \tag{10}$$

where the frictionless level of residual cash of fund f is given by

$$\Delta_f(0) \;=\; \underbrace{d_f}_{deposits} - \underbrace{B(R_*/r_*(f))^{\xi}w_f}_{repo\ lending},$$

and where we have defined

$$\bar{\lambda} \;=\; \sum_f \lambda_*(f)\Delta_f(0)\,.$$

In the presence of market power and imperfect competition in both repo and T-bill markets, the equilibrium T-bill rate, $\hat{\rho}$, deviates from its frictionless level given in equation (10). The following is true.

[15] All our results hold when banks are heterogeneous, but the equilibrium expressions become more complex.

Proposition 3.5 (Equilibrium T-bill rate) *The equilibrium T-bill rate depends negatively on the residual cash and, through this channel, it also depends negatively on the repo market concentration, as captured by $H(W)$.*

3.5 Equilibrium RRP choice

Our derivations in the previous sections are based on the assumption of upward-sloping demand curves (equation (6)) for T-bills. In particular, we take the coefficients $a_f, \lambda(f)$ of these demand functions as given, so we cannot explain funds' demand for RRP investments. In this section, we microfound this demand.

We assume that investing in RRP is associated with an implicit, non-monetary cost. For example, this cost might be driven by reputational concerns, whereby the fund fears its RRP investments might be interpreted as its inability to perform successful active investment choices. We assume that this cost is given by

$$\xi_f(\theta_f \Delta_f) \; + \; 0.5\beta_f(\theta_f \Delta_f)^2 \, , \tag{11}$$

where θ_f is the fraction of residual cash invested into RRP. In Appendix C, we use the formalism of Malamud and Rostek (2017) to develop a model of strategic trading for funds optimizing the tradeoff between price impact and the cost (11). First, larger residual cash implies that funds need to purchase more T-bills, increasing their price impact and making the market more illiquid. That is, Δ_f is an *endogenous* source of illiquidity in our model. The *exogenous* source of illiquidity in our model is the (in)elasticity of the demand curve (5) of liquidity providers; a drop in λ also leads to a drop in market liquidity. When the market is less liquid, funds optimally buy fewer T-bills and put more cash into RRP. Jointly, these observations imply that funds with larger residual cash Δ_f invest more into RRP, and more so when markets are illiquid. As a result, when T-bill markets are illiquid, funds' demand becomes less elastic with respect to changes in the T-bill rate.The following result formalizes this intuition.

Corollary 3.6 *The following is true.*

- *T-bill liquidity is negatively related to the residual cash* Δ_f*.*
- *A drop in* λ *leads to a drop in T-bill liquidity.*
- *A drop in T-bill liquidity leads to an increase in the share of residual cash invested in the RRP.*
- *Funds with larger residual cash* Δ_f *invest more into RRP, and more so when markets are illiquid.*
- *The elasticity of funds' T-bill investments with respect to the T-bill rate is negatively related to T-bill illiquidity.*

4 The aggregate impact of MMFs in the T-bill market

The model predicts that when MMFs have more residual cash left over from repo lending, the interest spread of T-bills over the RRP declines as they demand more T-bills. A natural implication of this is that a higher residual cash share also drives up the liquidity premium on T-bills. In this section we provide evidence consistent with these implications. We study the impact of a higher residual cash share on two interest rate spreads – the 1-month T-bill minus RRP spread and the 1-month GC repo minus 1-month T-bill spread. We establish causality through instrumental variables guided by our theory.

4.1 Data description and summary statistics

We collect data on monthly averages of the 1-month T-bill rate, the effective federal funds rate, the rate on the RRP facility, the 1-month GC repo rate, and the VIX. We also collect data on publicly held T-bills outstanding and GDP (we interpolate monthly data from available quarterly data) to construct monthly data for bills to GDP and subtract the holdings of the Federal Reserve through its SOMA portfolio. We obtain the monthly average of the Bloomberg Liquidity Index from Bloomberg. It is constructed from Treasuries with maturity longer than 1 year, therefore since MMFs can only hold instruments with shorter maturities, they do not have a direct impact on this index. Higher values correspond to lower liquidity.

Our key independent variable of interest, $residual\ cash\ share_t$, is defined as the share of aggregate MMF investments in T-bills and the RRP divided by the aggregate investments in bank repos, T-bills, and the RRP:

$$residual\ cash\ share_t = \left(1 - \frac{\sum_f repo_{f,t}}{\sum_f repo_{f,t} + Tbill_{f,t} + RRP_{f,t}}\right) \times 100.$$

The choice of using the share, rather then the amount of residual cash, follows from our model.[16]

Guided by our theory, we construct two instrumental variables for the residual cash share. First, $HHI\ bank\ repo$ measures the HHI of funds in the repo market, constructed by summing the squared market share of each fund in the repo market.[17] It lies between 0 and 10,000. Second, $HHI\ ex\ B^{*}T\ FE$ is constructed by first regressing contract values on bank-time fixed effects (i.e. changes in unobservable time-varying bank characteristics, including their demand for repos in a given month) and then constructing the HHI from the residual values. It also lies between 0 and 10,000. We discuss our instrumental variable strategy in more detail below.

Table 2 presents the summary statistics of our main variables over the 140 months in our sample period (2011m2 to 2022m12).

[16] In equilibrium, the MMFs face the problem of optimally splitting the residual cash between the T-bills and the RRP, given the implicit costs of using the facility. The actual cash amount invested into T-bills is a complex, endogenous quantity depending on the elasticity of MMF's demand, market liquidity, and other strategic considerations. As a result, our model predicts no directly testable link between the share of total funds invested into T-bills and the outcome variables (see, Proposition B.4). Instead, there is a direct link between the residual cash left over from repo lending and outcome variables.

[17] We define the Herfindahl-Hirschman index ('HHI') across fund market shares in the overall repo market as $HHI\ bank\ repo_t = \sum_{f=1}^{F} \left(\frac{bank\ repo_{f,t}}{bank\ repo_t} \times 100\right)^2$.

Table 2: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
Tbill (1M)-RRP	143	4.16	8.25	-16	33	2
GC-Tbill (1M)	143	12.84	9.66	-4.74	43.5	10.93
residual cash share	143	39.26	21.63	7.31	86.23	35
HHI bank repo	143	260.37	72.9	160.12	384.69	278.59
HHI ex B*T FE	143	265.07	82.02	140.82	407.95	292.08
FFR	143	.68	.88	.05	4.1	.14
log(bills to GDP)	143	-2.23	.28	-2.67	-1.42	-2.31
VIX	143	18.38	6.81	10.13	57.74	16.7
BBG Liq.	143	1.27	.48	.6	2.76	1.19

Note: This table reports the summary statistics for the main variables used in regressions in this section. $Tbill\ (1M) - RRP$ and $GC - Tbill\ (1M)$ are the dependent variables in basis points constructed as monthly averages of daily data. We use the 1-month T-bill and overnight RRP rates to calculate the $Tbill - RRP$ spread. Prior to the introduction of the RRP facility, we used the 1-month T-bill rate. $GC - Tbill$ spread is calculated using the 1-month GC repo rate minus the 1-month T-bill rate. *residual cash share* and ffr are measured in percentage points. HHI *bank repo* measures the HHI of funds in the repo market and is between 0 and 10,000 (constructed by summing the squared market share of each fund in the repo market). $HHI\ ex\ B^*T\ FE$ is constructed by taking out the bank-time fixed effects (mean bank demand in a given month) from each original contract value and then constructing the HHI from the values stripped out of average bank demand on a given month. It is also between 0 and 10,000. log(*bills to GDP*) is the log of total marketable bills held by the public minus bills held in the SOMA portfolio of the Federal Reserve. To construct monthly GDP data, we interpolate quarterly data into monthly data. VIX is the monthly average level of the index. P50 refers to the median. The sample is monthly time series between February 2011 and September 2022. *Data sources:* Crane Data, FRED, Bloomberg, US Treasury.

4.2 Residual cash from repo lending, market concentration, and the T-bill-RRP spread

To analyze the price impact of MMFs in the T-bill market, we estimate the following regression at the monthly level:

$$Tbill\ (1M) - RRP_t = \beta\ residual\ cash\ share_t + controls_t + \epsilon_t. \tag{12}$$

The dependent variable is the spread between the 1-month T-bill rate and the rate on the RRP facility in month t.[18] The variable $residual\ cash\ share_t$ captures the share of funds' AUM allocated to T-bills and the RRP facility. As controls, we include the Fed funds rate, the log of T-bill supply to GDP minus the holdings of the Federal Reserve in its SOMA portfolio, as well as the VIX, similar to Nagel (2016) and d'Avernas and Vandeweyer (2021). In addition, we account for the impact of Covid through a dummy for that takes on a value of one in the first four months of the pandemic. In all of our time series regressions, we report standard errors that are robust to arbitrary heteroskedasticity and autocorrelation with bandwidths selected according to the automatic lag selection procedure in Newey and West (1994).

The model predicts that a higher share of residual cash from repo lending has a negative effect on the spread, as funds' price impact exerts negative pressure on the T-bill rate, so $\beta < 0$. This follows directly from equation (10).

A concern for our analysis is that $residual\ cash\ share_t$ could be determined by forces other than MMFs' market power in the repo market. To establish a causal effect of the residual cash share on the Tbill-RRP spread, we leverage our model to devise an instrumental variable.

We instrument $residual\ cash\ share_t$ with the market concentration of MMFs in the repo market, i.e., $HHI\ bank\ repo_t$. According to our model, greater concentration in the repo market means that funds charge on average higher rates, thereby reducing banks' demand for repos. In turn, funds have more residual cash to invest in T-bills – driving down the T-bill rate. As we will show below, there is a strong and statistically significant correlation (at 1%) between the HHI and the cash share.

The exclusion restriction is that market concentration in the repo market is not determined by other (unobservable) factors also affecting the T-bill rate. One potential concern is that the HHI is determined by factors that change banks' demand for repos from specific funds, and also affect the T-bill rate.[19] Addressing this concern requires us to construct an HHI index that is

[18] The RRP rate was only operationalized towards the end of 2013 and paid close to zero when the economy was at the zero lower bound. We use the T-bill rate prior to the introduction of the RRP.

[19] Note that the exclusion restriction would only be violated if the unobservable factors systematically affect banks' demand for repos with large funds differently from smaller funds.

not driven by changes in banks' demand for repos. We therefore purge the the HHI purged from unobservable time-varying bank characteristics, including their demand for repos in each month, through bank*time fixed effects. We then estimate regressions with $HHI\ ex\ B^{*}T\ FE$, constructed from the residuals, as instrument.

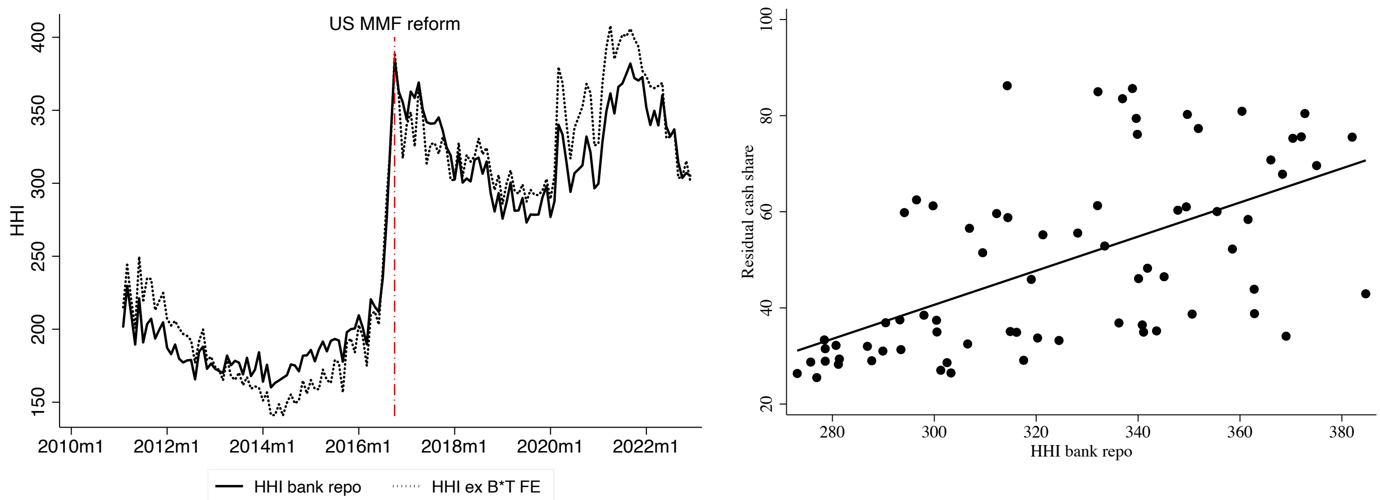
A second concern is that the HHI mostly reflects the variation induced by the MMF reform in 2016 (see Figure 3, panel a). The 2016 MMF reform was implemented in response to the repeated episodes of stress in this market during the GFC and the Eurozone crisis and required prime institutional funds and municipal funds to switch to a floating net asset value (NAV) calculation. It also introduced the possibility of imposing redemption gates and fees at the discretion of the fund. Government and treasury funds, on the other hand, were allowed to operate with stable NAVs and without any redemption gates or fees. An unintended consequence of the reform was drastically increased concentration in the repo market (Aldasoro, Ehlers and Eren (2022)).

A threat to identification is that as resources moved from prime to government funds after the reform, not only the HHI but also the aggregate demand for repos increased, as government funds cannot invest in unsecured instruments. An increase in demand for repos not matched by greater supply would be associated with higher repo rates, but also more residual money that MMFs have to put somewhere. Should government funds invest this residual money into T-bills or the RRP, the exclusion restrictions would be violated. To address this concern, we also estimate OLS and IV regressions only for the months after the reform.[20].

Table 3 reports results. Our first result is that adding *residual cash share* to the variables that are commonly used in the literature, such as the federal funds rate, log(bills to GDP), and VIX, substantially increases the R^2. Specifically, it increases from 25% in column (1), which uses standard variables, to 41% in column (2), where we add the residual cash share. Interestingly, adding the residual cash share does not affect the sign or size of the coefficients on the federal funds rate, log(bills to GDP), or the VIX, but it does increase the estimated coefficient on the impact

[20] Note that there is also a stronger positive correlation between the HHI and the residual cash share also in the sample restricted to the months after the reform as illustrated with a much higher first stage F-statistic

Figure 3: HHI for funds in the repo market and residual cash share



(a) HHI of the repo market **(b)** HHI and residual cash share correlation

Notes: *HHI bank repo* measures the HHI of funds in the repo market and is between 0 and 10,000 (constructed by summing the squared market share of each fund in the repo market). *HHI ex B*T FE* is constructed by taking out the bank-time fixed effects (mean bank demand in a given month) from each original contract value and then constructing the HHI from the values stripped out of average bank demand on a given month. it is also between 0 and 10,000. $residual\ cash\ share_t$ is constructed using the monthly MMF holdings data. For each fund on a given date, we subtract from one the share of repo lending to banks, which is one minus the total amount invested in repos with banks divided by the total amount invested in repos with banks, T-bills, and the RRP facility. We then average this across MMFs each month. Source: Crane Data.

of T-bill supply. Second, and as predicted by our theory, the residual cash share has a significant negative effect on the Tbill-RRP spread.

To estimate the causal effect of the *residual cash share* on the Tbill-RRP spread, we use *HHI bank repo* as IV. Column (3) present the first stage regression and shows a highly statistically significant correlation with *residual cash share*, so the instrument is relevant. Column (4) presents the 2SLS result and shows a highly significant negative effect of the instrumented residual cash share on the spread. Quantitatively, the partial impact of a one standard deviation increase in *residual cash share* on $Tbill\ (1M) - RRP_t$ is slightly more than five basis points (more than half a standard deviation). This effect is equivalent to the partial impact of a one percentage point increase in the federal funds rate, or a one-third of a percent increase in the partial impact of bills-to-GDP.

Table 3: MMFs' residual cash share and the T-bill-RRP spread

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			1st St.	2nd St.		2nd St.	
	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
VARIABLES	Tbill (1M)-RRP	Tbill (1M)-RRP	residual cash share	Tbill (1M)-RRP	Tbill (1M)-RRP	Tbill (1M)-RRP	Tbill (1M)-RRP
residual cash share		-0.18***		-0.25***	-0.29***	-0.30***	-0.41***
		(0.03)		(0.05)	(0.07)	(0.11)	(0.13)
HHI bank repo			0.16***				
			(0.05)				
FFR	3.65**	4.34***	-1.02	4.58***	4.72***	4.21***	3.93***
	(1.74)	(1.11)	(4.75)	(1.03)	(1.00)	(1.11)	(0.91)
log(bills to GDP)	9.35***	16.13***	11.31	18.48***	19.91***	18.84***	20.94***
	(3.26)	(2.13)	(9.60)	(2.62)	(3.30)	(3.53)	(4.66)
VIX	-0.15	-0.09	0.53	-0.07	-0.06	0.08	0.24
	(0.15)	(0.09)	(0.70)	(0.12)	(0.13)	(0.35)	(0.42)
Covid	1.54	-0.02	-12.75	-0.56	-0.89	-4.46	-8.44
	(3.99)	(2.44)	(17.17)	(2.80)	(3.19)	(8.11)	(10.17)
Observations	143	143	143	143	143	75	75
R-squared	0.25	0.41	0.45				
Exc. Instrument				HHI	HHI ex B*T FE	HHI	HHI ex B*T FE
Underidentification test (p-val)				0.05	0.12	0.06	0.13
Anderson-Rubin test (p-val)				0.00	0.01	0.02	0.01
Kleibergen-Paap rk Wald F stat				10.56	5.23	69.59	8.73

Note: This table reports results of various regressions with alternative specifications of the equation (12). Variable descriptions and summary statistics can be found in Table 2. Data are at a monthly frequency between February 2011 and September 2022. Columns (1) and (2) report the results of OLS regressions. Columns (3) and (4) report the first and second stages of a 2SLS regression, in which *HHI bank repo* instruments *residual cash share*. In column (5), we report the second stage in which we instrument *residual cash share* by *HHI ex B*T FE*. Columns (6) and (7) replicate columns (4) and (5), but restrict the sample to the months after the MMF reform in October 2016. Wherever applicable, we report the p-values of the underidentification test, the Anderson-Rubin test, and the Kleibergen-Paap rk Wald F statistic of the first stage. Standard errors are robust to arbitrary heteroskedasticity and autocorrelation with the lag structure automatically selected using the Newey and West (1994) procedure. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data, FRED, US Treasury.

Column (5) addresses the concern that the HHI could be determined by unobservable factors correlated with bank demand and the Tbill rate. It re-estimates column (4), but with the HHI *ex* B^*T FE instead of the HHI *bank repo* as an instrument. The estimated coefficient is similar and remains statistically significant at the 1% level.

Finally, column (6) focuses on the months after October 2016, ie after the implementation of the MMF reform. Using HHI *bank repo* as an instrument, we again find a highly significant and negative effect of the residual cash share on the spread. The F-statistic for the restricted sample is 69.6. Column (7) confirms these results with the HHI *ex* B^*T FE as an instrument. These results mitigate the concern that the reform, which raised the HHI, could have led to an increase in the aggregate demand for repos by government funds and thereby affected the T-bill rate through channels other than the residual cash share.

4.3 MMFs' aggregate impact on the liquidity premium

We now turn to the liquidity premium, which is the premium paid by investors for the liquidity services provided by US Treasuries, and in particular, T-bills. Because of the importance US Treasuries in global finance, changes in their liquidity have consequences for the US and global markets. The liquidity premium has hence fostered an important body of research both in macroeconomics (e.g. Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2016) and in international finance (e.g. Jiang, Krishnamurthy and Lustig, 2021; Engel and Wu, 2021).

An implication of the model predictions is that the more assets funds allocate to T-bills, the more the liquidity premium, measured by the GC repo-T-bill spread, will increase. The reason is that funds' price impact reduces the the T-bill rate (see also results in Table 3). We test this implication in Table 4.

As a baseline, in column (1) of Table 4, we run a similar regression to those in Nagel (2016) and d'Avernas and Vandeweyer (2021) for our monthly sample. In column (2), we add *residual cash share* to the baseline OLS regression. According to the estimates, the marginal effect of the cash share is economically sizable and statistically significant at the 5% level. Moreover, it improves the fit considerably, as the R^2 increases from 37% to 45%.

In column (3), we report the two-stage least squares results with *HHI bank repo*.[21] While the point estimates are larger in the IV regression, statistical significance declines to the 10% level. The estimates suggest that the partial effect of a one standard deviation change in *residual cash share* is equivalent to a 125 basis point increase in the federal funds rate or a one-fifth of a percent increase in bills-to-GDP.

[21] A word of caution is for the use of instrumental variables with the GC-T-bill spread on the left-hand side. MMFs account for a relatively small share of aggregate dollar repo markets, and GC repo is predominantly between securities dealers. Therefore, we do not expect a direct effect of MMF market concentration on GC repo. However, it is hard to observe or rule out whether there might be indirect effects that might violate the exclusion restriction for the HHI in the MMF-bank repo lending market due to the very opaque nature of repo markets other than those between MMFs and banks.

Table 4: MMFs' residual cash share and Treasury market liquidity

	(1)	(2)	(3)
	OLS	OLS	2SLS
VARIABLES	GC-Tbill (1M)	GC-Tbill (1M)	GC-Tbill (1M)
residual cash share		0.13**	0.25*
		(0.06)	(0.15)
FFR	4.17***	4.04***	3.91***
	(1.21)	(1.22)	(1.44)
log(bills to GDP)	-18.71***	-23.42***	-27.92***
	(3.89)	(4.78)	(6.17)
VIX	0.27	0.25*	0.24*
	(0.20)	(0.14)	(0.13)
Observations	140	140	140
R-squared	0.36	0.42	
Exc. Instrument			HHI
Underidentification test (p-val)			0.01
Anderson-Rubin test (p-val)			0.02
Kleibergen-Paap rk Wald F stat			15.18

Note: This table reports results of various regressions with alternative specifications of the equation (12) with the liquidity premium as the dependent variable. Variable descriptions and summary statistics can be found in Table 2. Data are at a monthly frequency between February 2011 and September 2022. Columns (1) and (2) report the results of OLS regressions. Column (3) reports the second stage estimates of a 2SLS regression, in which *HHI bank repo* instrument *residual cash share*,. Wherever applicable, we report the p-values of the under-identification test and the Anderson-Rubin test and the Kleibergen-Paap rk Wald F statistic of the first stage. Standard errors are robust to arbitrary heteroskedasticity and autocorrelation with the lag structure automatically selected using the Newey and West (1994) procedure. *** p<0.01, ** p<0.05, * p<0.1. Source: Crane Data, FRED, US Treasury.

In sum, results in Table 3 and 4 provide strong support for the predictions of our model. Higher concentration in the repo market implies a negative effect on the T-bill rate, thereby increasing the liquidity premium.

5 MMFs' portfolio allocation and the trade-off between market power and price impact

In this section, we test the two key implications of the model using the contract-level data. The first prediction (Proposition B.3) is that, on the one hand, higher market power allows MMFs to charge higher repo rates to banks. On the other hand, if funds have a large share in the T-bill market, they internalize their price impact in the T-bill market by charging lower repo rates. Our second key prediction (see Corollary 3.6) is that the allocation between T-bills and RRP favors RRP when the T-bill market is illiquid and therefore, the price impact in the T-bill market is greater.

5.1 Data description

We use a granular and rich dataset of US MMFs' portfolio holdings at month-ends obtained from Crane Data, which is based on the regulatory filings of US MMFs to the Securities and Exchange Commission (SEC N-MFP forms). The sample covers the universe of US MMF funds between February 2011 and November 2022. Holdings data are reported at each month's end.[22] For each holding, the dataset provides information on the face value in dollar amounts, the instrument, the remaining maturity, and the (annualized) yield, among other contract characteristics. In addition, for repos, we observe whether the borrowing is backed by either Treasury, Government Agency, or Other collateral. By law, US MMFs are only allowed to invest in dollar-denominated instruments. Therefore, all transactions are denominated in dollars.

To measure funds' market share ('FMS') in repos with banks and the T-bill market, we define

[22] We use the same data cleaning procedure as in Aldasoro, Ehlers and Eren (2022). We refer the interested reader to that paper.

the following two metrics:

$$FMS\ bank\ repo_{f,t} = \frac{\sum_b bank\ repo_{f,b,t}}{\sum_f \sum_b bank\ repo_{f,b,t}} \times 100, \tag{13}$$

$$FMS\ treasury_{f,t} = \frac{amount\ treasury_{f,t}}{\sum_f amount\ treasury_{f,t}} \times 100, \tag{14}$$

where f denotes fund, b bank, and t the month. Higher values of $FMS\ bank\ repo$ ($FMS\ treasury$) proxy greater market power of a fund in the bank lending (T-bill) market.

Table 5: Summary statistics

Panel (a): Summary statistics for variables in Table 6 (contract level data)

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
rate	266382	87.75	92.88	0	550	38
FMS bank repo	266382	1.84	2.12	0	11.89	.82
FMS treasury	266382	.81	1.15	0	15.72	.29

Panel (b): Summary statistics for variables in Table 7 (fund-time level data)

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
RRP share	12997	16.94	30.75	0	99.87	0
FMS treasury	12997	.44	.87	0	10.53	.09
liqu tight (BBG index)	12997	1.3	.48	.67	2.76	1.25

Note: This table reports summary statistics for the key variables used in the empirical analysis. Using contract-level data, the upper panel reports the summary statistics of the variables used in Table 6. The sample period for the upper panel runs between February 2011 and November 2022, with holdings data reported at each month's end. *rate* refers to the repo rate and is in basis points. $FMS\ bank\ repo$ is the market share of the fund in the repo market (see Eq. 13) $FMS\ treasury$ is the market share of the fund in the T-bill market (see Eq. 14). Both of these variables are in percentage points. In the lower panel, we report the summary statistics of the variables used in Table 7 at the fund-time level. The sample period for the lower panel runs between October 2013 and November 2022 (i.e., after the introduction of the RRP facility). $RRP\ share$ is the share a fund allocates between T-bills and the RRP facility. $FMS\ treasury$ is the market share of the fund in the T-bill market (see Eq. 14). Both of these variables are in percentage points. *liqu tight* ($BBG\ index$) is the Bloomberg liquidity index which measures the average deviation of yields from a fair-value model. A higher number indicates lower liquidity. Source: Crane Data, Bloomberg.

5.2 Tests

We first analyze the effects of funds' market shares ('FMS') in the repo market with banks and the T-bill market on repo rates charged to banks (Proposition B.3). We estimate variants of the following regression:

$$rate_{i(f,b),t} = \beta_1 \; FMS\ bank\ repo_{f,t} + \beta_2 \; FMS\ treasury_{f,t} + controls_{i,t} + \theta_t + \varepsilon_{i,t}. \qquad (15)$$

The dependent variable $rate_{i(f,b),t}$ is the annualized interest rate in basis points on a contract i between fund f and bank b at time t. The explanatory variables $FMS\ bank\ repo_{f,t}$ and $FMS\ treasury_{f,t}$ denote fund f's market share in the bank repo and the T-bill markets in t (as defined in Equations (13) and (14)). To account for time-varying factors that affect different collateral types (US Treasury, government agency, or other collateral), the baseline regression includes time-varying fixed effects at the collateral type level (θ_t). Control variables are the size and the maturity of the contract. Standard errors are double clustered at both fund and time levels.

Proposition B.3 states that both market power and funds' internalization of their price impact in the T-bill market should enter into their consideration when setting repo rates. In particular, funds with greater market power (proxied by fund market share or FMS bank repo) in the repo market charge higher rates, while a greater market share in the T-bill market lower the repo rates charged by the same fund due to the internalization of the price impact. We hence expect that $\beta_1 > 0$ and $\beta_2 < 0$.

Regression equation (15) faces the identification challenge that the observed rate could be determined by observable or unobservable time-varying factors that vary at the fund type (prime, government, or Treasury fund) or bank level. For example, if funds with a greater market share in the bank lending market lend to riskier banks, then any observed positive correlation between *FMS bank repo* and the rate reflects borrower characteristics, rather than market power. Moreover, prime funds might be subject to different shocks than government or treasury funds, which could influence the repo rate. As we will discuss in what follows, we address these identification challenges through the inclusion of granular time-varying fixed effects.

Table 6 shows that funds with a higher market share in the repo market charge higher repo rates, while, all else constant, funds with a higher market share in the T-bill market charge lower rates.[23] Column (1) reports a positive coefficient on FMS *bank repo* ($\beta_1 > 0$) significant at the 5% level, and a negative coefficient on FMS *treasury* ($\beta_2 < 0$) significant at the 1% level. Column (2) shows that this pattern is robust to the inclusion of fund type*time fixed effects that account for any unobservable shocks that affect different fund types. Both coefficients are now significant at the 1% level.

To account for unobservable time-varying differences in bank characteristics, including changes in risk, size, or credit demand, column (3) includes bank*time fixed effects. Note that these fixed effects absorbs any market power banks might have in this market (see, e.g. Aldasoro, Ehlers and Eren, 2022; Huber, 2022) and show the market power of MMFs when bank market power is held constant. Both coefficients keep their sign and significance and change only marginally in size. The stability of the coefficients suggests that unobservable borrower characteristics do not explain the correlation between fund market power and rates. In column (4) we include the log amount of a contract and finely-grained fixed effects for different maturities to control for the fact that rates could be correlated with the amount and maturity. Results show that even when we compare contracts of similar amounts and with comparable maturity, funds with a higher market share in the repo market still charge higher repo rates and a higher market share in the T-bill markets corresponds to lower repo rates. Finally, column (5) further allows any unobservable time-varying shock at the bank- or fund type-level to affect each collateral type differentially in each month. Yet our baseline result remains robust even when we include bank*collateral*time and fund type*collateral*time fixed effects. In column (6), we repeat column (5), but using fund family market shares in the repo ($FFMS$ *bank repo*) and T-bill market ($FFMS$ *treasury*) instead of fund market shares. This accounts for the possibility that negotiations with banks take place at the fund family levels instead of fund level and we obtain similar results.

In terms of magnitude, in column (5) the partial impact of a 2 percentage point increase in the

[23] While we focus on market power and share in the T-bill market at the fund level, our results are similar if we instead run the regressions at the fund family level

Table 6: Funds have market power in the repo market, but also internalize their price impact in the T-bill market

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	rate	rate	rate	rate	rate	rate
FMS bank repo	0.209**	0.357***	0.296***	0.273***	0.217***	
	(0.105)	(0.109)	(0.091)	(0.088)	(0.082)	
FMS treasury	-0.495***	-0.590***	-0.596***	-0.557***	-0.476***	
	(0.150)	(0.152)	(0.143)	(0.132)	(0.136)	
FFMS bank repo						0.105***
						(0.035)
FFMS treasury						-0.103*
						(0.054)
Observations	266,382	266,382	266,195	266,178	265,488	369,006
R-squared	0.957	0.958	0.963	0.967	0.970	0.966
collateral*time FE	✓	✓	✓	✓	-	-
fund type*time FE	-	✓	✓	✓	-	-
bank*time FE	-	-	✓	✓	-	-
fund type*collateral*time FE	-	-	-	-	✓	✓
bank*collateral*time	-	-	-	-	✓	✓
controls	-	-	-	✓	✓	✓

Note: This table reports the results of the regressions for alternative specifications of equation (15). Variable descriptions and summary statistics can be found in Table 5. The unit of observation is a contract between a fund and a bank reported as part of the disclosure of MMFs' portfolio holdings snapshot at month ends between February 2011 and November 2022. In column (1), we include collateral*time fixed effects. Collateral categories are US Treasury, government agency, and other collateral. In column (2), we add fund type*time fixed effects. Fund type categories are government, Treasury, and prime funds catered to retail or institutional investors. In column (3), we add bank*time fixed effects. In column (4), we add control variables which are the log contract size and fixed effects of finely-grained maturity buckets interacted with time. In column (5), we include fund type*collateral*time and bank*collateral*time fixed effects as well as control variables. In column (6), we repeat column (5), but using market shares in the repo and T-bill market at the fund family level instead of fund level. Standard errors, double clustered at fund and time level, are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data.

fund market share in the repo market (roughly one standard deviation) corresponds to a 42 basis points higher repo rate. This is economically important given the overall mean of repo rates is 88 basis points. Similarly, a 1 percentage point increase in the share of a fund among other MMFs in the T-bill market (again roughly one standard deviation), leads to a 47 basis points lower repo rate. These results suggest that MMFs substantially internalize their price impact in the T-bill market when they are setting repo rates.

Next, we turn to Prediction 2 (Corollary 3.6), which states that the share of residual cash left over from repo lending allocated to overnight RRP is higher for funds with a higher share in the T-bill market, and in particular when Treasury market liquidity is low.

To test this prediction, we estimate regressions at the fund f-month t level:

$$RRP\ share_{f,t} = \delta_1\ FMS\ treasury_{f,t} + \delta_2\ liquidity\ tightness_t + \delta_3\ FMS\ treasury_{f,t} \times liquidity\ tightness_t + controls_{f,t} + \theta_t + \varepsilon_{f,t}. \tag{16}$$

The dependent variable $RRP\ share_{f,t}$ is the share of cash left over from repo lending allocated to RRP as opposed to T-bills for fund f at time t. The explanatory variable $FMS\ treasury_{f,t}$ denotes fund f's market share in the T-bill market in t (as defined in Equation (14)). The variable $liquidity\ tightness_t$ measures liquidity conditions in the overall Treasury market, measured by the average deviation of yields from a fair-value model for maturities longer than a year, with higher values indicating lower liquidity (proxied by the Bloomberg Liquidity Index). Note that since MMFs cannot hold assets with such long maturities, they do no have any direct impact on this liquidity index. To account for time-varying factors that affect all funds, the baseline regression includes time-fixed effects (θ_t) as we progressively saturate the regressions with more fixed effects and control variables. Standard errors are double clustered at the level of both fund and time. Prediction 2 states that funds with greater market power in the T-bill market allocate a greater share of their assets to RRP, especially when liquidity conditions in the Treasury market are worse ($\delta_3 > 0$).

Table 7 shows results consistent with Prediction 2. Column (1) includes only $FMS\ treasury$ as the dependent variable and shows a highly significant positive relationship between a fund's market share in the T-bill market and the share of assets allocated to RRP. This correlation remains unaffected when we include time-fixed effects in column (2). In terms of magnitude, a 1 percentage point higher T-bill market share is associated with a 4.3 percentage point higher RRP share of the total residual cash left over from repo lending and invested between T-bills and RRP (corresponding to around a fourth of the mean RRP share). Column (3) introduces the interaction term of $FMS\ treasury$ with *liquidity* and shows a positive coefficient on the interaction term, significant at the 1% level. Column (4) adds fund-fixed effects to control for any unobservable fund-specific characteristics. Column (5) adds fund type*time fixed effects to control for any time-varying differences across different fund types as well as control variables such as the log change in the assets under management and interaction of FMS *treasury* with the 1-month T-bill rate and the federal funds rate separately. In column (6) we hence replicate column (5) but use the *change* in the liquidity indicator as the explanatory variable. We obtain similar results.

Across specifications, the sign and significance of our coefficients of interest remain similar, suggesting that the predicted relationship between fund market share, liquidity, and the RRP share is not due to unobservable fund characteristics, nor time-varying shocks that affect different fund types, nor changes in the assets under management, nor reflecting changes in the Fed funds rate or T-bill rate that could affect funds with different market shares differentially.

6 Policy implications

Our results have policy implications for the transmission of monetary policy and benchmark rates.

First, MMFs typically receive inflows when the federal funds rate is higher (e.g. Duffie and Krishnamurthy, 2016; Drechsler, Savov and Schnabl, 2017; Xiao, 2020). Therefore, the market power-price impact trade-off could lead to downward pressure on T-bill rates during these episodes, weakening the effectiveness of interest rate policy. This effect might also transmit to the long end of the yield curve due to the high sensitivity of long-term rates to short-term rates (Hanson, Lucca and Wright, 2021) and might lead to negative externalities if it incentivizes private money creation (Greenwood, Hanson and Stein, 2015).

Second, a smaller central bank balance sheet would mean a smaller role for the RRP facility. This would intensify the price impact of MMFs on T-bill rates, and arguably especially so during flight-to-quality episodes in which MMFs receive large inflows. For example, during the Covid-19 crisis, government and Treasury MMFs received close to $1 trillion inflows within weeks (e.g. Eren, Schrimpf and Sushko, 2020b).

Table 7: **Treasury market liquidity and the share of residual cash going to RRP**

VARIABLES	(1) RRP share	(2) RRP share	(3) RRP share	(4) RRP share	(5) RRP share	(6) RRP share
FMS treasury	3.758***	4.355***	-3.721**	-11.582***	-10.665***	-4.700***
	(1.189)	(1.130)	(1.843)	(2.421)	(2.090)	(1.186)
FMS treasury × liqu tight			6.620***	5.412***	5.312***	
			(2.067)	(1.272)	(1.397)	
FMS treasury × Δ liqu tight						8.973***
						(3.052)
Observations	12,997	12,997	12,997	12,980	11,865	11,774
R-squared	0.011	0.243	0.251	0.606	0.653	0.652
time FE	-	✓	✓	✓	-	-
fund FE	-	-	-	✓	✓	✓
fund type*time FE	-	-	-	-	✓	✓
controls	-	-	-	-	✓	✓

Note: This table reports the results of the regressions for alternative specifications of equation (16). Variable descriptions and summary statistics can be found in Table 5. Observations are at the fund-time level constructed from the holding level data reported as part of the disclosure of MMFs' portfolio holdings snapshot at month ends between the introduction of the RRP facility in October 2013 and November 2022. In column (1), we run a simple bivariate OLS regression. In column (2), we include time-fixed effects. In column (3), we include the interaction between FMS *treasury*, which measures the share of an individual fund among all MMFs in the T-bill market, and *liqu tight*, which is the Bloomberg Liquidity Index (higher values correspond to lower liquidity in the entire Treasury market). In column (4), we further add fund fixed effects. In column (5), we further add fund type*time fixed effects and several control variables at the fund-time level (log change in AUM, the interaction between FMS *treasury* and the federal funds rate as well as the 1-month T-bill rate). In column (6), we repeat column (5) but replace *liqu tight* with Δ*liqu tight*, which measures the changes in the Bloomberg Liquidity Index. Standard errors, double clustered at fund and time level, are in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Source: Crane Data.

Third, as the transition from credit-sensitive benchmark rates to risk-free repo-based benchmark rates is underway (Huang and Todorov, 2022), an often-mentioned reason for this transition is to have "a more resilient rate than LIBOR because of [...] the depth and liquidity of the markets that underlie it" (ARCC, 2021).[24] We show that new benchmark rates could also be affected by the market structure and liquidity conditions in repo and Treasury markets which could have large spillover effects to many other markets in which these benchmark rates are used.

Finally, our results imply that market concentration in the MMF sector has broader conse-

[24]The Alternative Reference Rates Committee (ARRC) is a group of private-market participants convened by the Federal Reserve Board and the New York Fed to help ensure a smooth transition from LIBOR to Secured Overnight Financing Rate (SOFR).

quences for the macroeconomy through its effect on short-term money market interest rates and spreads. As a result, policy reforms that have impacted market concentration might have had unintended consequences such as the reduction of T-bill rates and an increase in the liquidity premium.

7 Conclusion

We show that repo markets and T-bill markets are connected through the large presence of MMFs in both markets. MMFs have market power in the repo market, but they are also large in the T-bill market. As a result, they also have a price impact on the T-bill market. They set repo rates with banks and interact with other MMFs in the T-bill market. Strategic and optimal price setting, and portfolio choice determine how key interest rates and spreads are determined in equilibrium and how MMFs allocate their portfolio between repos with banks, the Federal Reserve, and T-bills. The key drivers of these choices are frictions due to market concentration in the repo market and liquidity conditions in the T-bill market. Our results suggest that monetary policy transmission can weaken due to these frictions, central bank balance sheet size plays an important role in affecting MMFs' trade-offs and macroeconomic outcomes, and these market frictions can have spillovers.

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A Additional figures and tables

B Proofs

Proof of Lemma 4. In the presence of internalization, we get that MMF is maximizing

$$\frac{r_f(b)^{-\alpha_b} w_f}{r_f(b)^{-\alpha_b} w_f \ + \ F_{-f}(b)} (R_*^{\xi} r_f(b)^{1-\xi} - \rho R_*^{\xi} r_f(b)^{-\xi})$$

which is equivalent to maximizing

$$\frac{r_f(b)^{1-\alpha_b-\xi} - \rho r_f(b)^{-\alpha_b-\xi}}{r_f(b)^{-\alpha_b} w_f \ + \ F_{-f}(b)},$$

and the first order condition is

$$\begin{aligned}
&((1-\alpha_b-\xi) r_f(b)^{-\alpha_b-\xi} + (\alpha_b+\xi)\rho r_f(b)^{-\alpha_b-\xi-1})(r_f(b)^{-\alpha_b} w_f \ + \ F_{-f}(b)) \\
&+ \alpha_b r_f(b)^{-\alpha_b-1} w_f (r_f(b)^{1-\alpha_b-\xi} - \rho r_f(b)^{-\alpha_b-\xi})) \ = \ 0
\end{aligned}$$

which is equivalent to

$$\begin{aligned}
&((1-\alpha_b-\xi) r_f(b) + (\alpha_b+\xi)\rho) \\
&+ \frac{\alpha_b r_f(b)^{-\alpha_b} w_f (r_f(b)-\rho)}{r_f(b)^{-\alpha_b} w_f \ + \ F_{-f}(b)} \ = \ 0
\end{aligned}$$

so that

$$r_f(b) \ = \ r_*(b) \ + \ \frac{1}{\alpha_b+\xi-1} \frac{\alpha_b r_f(b)^{-\alpha_b} w_f (r_f(b)-\rho)}{\Gamma_*(b)}.$$

Q.E.D.

Proposition B.1 (Equilibrium in the repo market) *Suppose that* $w_f = w_f^*/F$, *where* w_f^* *are uniformly bounded. For simplicity, we normalize* $\sum_f w_f^* = F$.[25] *Define*

$$H(W) \ = \ F^{-1} \sum_f (w_f^*)^2$$

[25] E.g., the most competitive case corresponds to an equal distribution of size across funds, $w_f^* = 1/F$, with $H(W) = 1/F$, the lowest possible value.

to be the Herfindahl index of the fund size distribution. Then,

$$r_f(b) \;=\; r_*(b) \;+\; F^{-1} r_f^{(1)}(b) \;+\; F^{-2} r_f^{(2)}(b) \;+\; O(F^{-3}),$$

with

$$r_f^{(1)}(b) \;=\; \frac{w_f^* \alpha_b}{\alpha_b + \xi - 1}(r_*(b) - \rho)$$

and

$$r_f^{(2)}(b) = \underbrace{\left(\frac{w_f^* \alpha_b}{\alpha_b + \xi - 1}\right)^2 (1 - \alpha_b r_*(b)^{-1}(r_*(b) - \rho))(r_*(b) - \rho)}_{\textit{own market power convexity adjustment}}$$
$$+ \underbrace{\frac{w_f^* \alpha_b^2 r_*(b)^{-1}}{(\alpha_b + \xi - 1)^2}(r_*(b) - \rho)^2 H(W)}_{\textit{market concentration}}$$

Proof of Proposition B.1. We have

$$r_f(b) \;=\; r_*(b) \;+\; F^{-1} r_f^{(1)}(b) \;+\; F^{-2} r_f^{(2)}(b) \;+\; O(F^{-3}).$$

Our goal is to find $r_f^{(1)}(b)$, $r_f^{(2)}(b)$. Substituting, we get

$$\begin{aligned}
\Gamma_*(b) \;&=\; F^{-1} \sum_f r_f(b)^{-\alpha_b} w_f^* \\
&=\; F^{-1} \sum_f w_f^* \left(r_*(b) \;+\; F^{-1} r_f^{(1)}(b) \;+\; F^{-2} r_f^{(2)}(b) \;+\; O(F^{-3}) \right)^{-\alpha_b} \\
&=\; F^{-1} \sum_f w_f^* \Bigg(r_*(b)^{-\alpha_b} \;-\alpha_b r_*(b)^{-1} \Big(F^{-1} r_f^{(1)}(b) \;+\; F^{-2} r_f^{(2)}(b) \;+\; O(F^{-3}) \Big) \\
&\;+\; 0.5 \alpha_b (\alpha_b + 1) r_*(b)^{-2} F^{-2} (r_f^{(1)}(b))^2 \Bigg) \\
&=\; r_*(b)^{-\alpha_b} \;-\; F^{-1} \alpha_b r_*(b)^{-1-\alpha_b} E[r_f^{(1)}(b)] \\
&\;+\; F^{-2} \alpha_b r_*(b)^{-1-\alpha_b} \Big(0.5(\alpha_b + 1) r_*(b)^{-1} E[(r_f^{(1)}(b))^2] - E[r_f^{(2)}(b)] \Big) \;+\; O(F^{-3}) \\
&=\; r_*(b)^{-\alpha_b} \;+\; \Gamma_*(b)^{(1)} F^{-1} \;+\; \Gamma_*(b)^{(2)} F^{-2} \;+\; O(F^{-3}).
\end{aligned}$$

Substituting this gives

$$O(F^{-3}) + r_f(b) \;=\; r_*(b)$$

$$+\;\; \frac{1}{\alpha_b+\xi-1}\frac{\alpha_b\Big(r_*(b) \;+\; F^{-1}r_f^{(1)}(b) \;+\; F^{-2}r_f^{(2)}(b)\Big)^{-\alpha_b} w_f\Big(\Big(r_*(b) \;+\; F^{-1}r_f^{(1)}(b) \;+\; F^{-2}r_f^{(2)}(b)\Big) - \rho\Big)}{r_*(b)^{-\alpha_b} \;+\; \Gamma_*(b)^{(1)}F^{-1} \;+\; \Gamma_*(b)^{(2)}F^{-2}}$$

$$=\; r_*(b) \;+\; F^{-1}\frac{1}{\alpha_b+\xi-1}\alpha_b r_*(b)^{-\alpha_b}\Big(1 \;-\; F^{-1}r_f^{(1)}(b)r_*(b)^{-1}\alpha_b\Big)w_f^*\Big(\Big(r_*(b) \;+\; F^{-1}r_f^{(1)}(b)\Big) - \rho\Big)$$

$$\times\, r_*(b)^{\alpha_b}\left(1 \;-\; r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)}F^{-1}\right)$$

$$=\; r_*(b) \;+\; F^{-1}\frac{w_f^*\alpha_b}{\alpha_b+\xi-1}\Big(1 \;-\; F^{-1}r_f^{(1)}(b)r_*(b)^{-1}\alpha_b - r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)}F^{-1}\Big)\Big(\Big(r_*(b) \;+\; F^{-1}r_f^{(1)}(b)\Big) - \rho\Big)$$

$$=\; r_*(b) \;+\; F^{-1}\frac{w_f^*\alpha_b}{\alpha_b+\xi-1}\Big((r_*(b)-\rho) \;+\; F^{-1}\Big(r_f^{(1)}(b) - (r_f^{(1)}(b)r_*(b)^{-1}\alpha_b + r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)})(r_*(b)-\rho)\Big)\Big)$$

$$=\; r_*(b) \;+\; F^{-1}\frac{w_f^*\alpha_b}{\alpha_b+\xi-1}\Big((r_*(b)-\rho) \;+\; F^{-1}\Big(r_f^{(1)}(b) - (r_f^{(1)}(b)r_*(b)^{-1}\alpha_b + r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)})(r_*(b)-\rho)\Big)\Big)$$

Thus,

$$r_f^{(1)}(b) \;=\; \frac{w_f^*\alpha_b}{\alpha_b+\xi-1}(r_*(b)-\rho)$$

and

$$r_f^{(2)}(b) \;=\; \frac{w_f^*\alpha_b}{\alpha_b+\xi-1}\Big(r_f^{(1)}(b) - (r_f^{(1)}(b)r_*(b)^{-1}\alpha_b + r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)})(r_*(b)-\rho)\Big)$$

and

$$\Gamma_*(b)^{(1)} \;=\; -\alpha_b r_*(b)^{-1-\alpha_b}E[r_f^{(1)}(b)] \;=\; -\alpha_b r_*(b)^{-1-\alpha_b}E[\frac{w_f^*\alpha_b}{\alpha_b+\xi-1}(r_*(b)-\rho)]$$

$$=\; -\,\alpha_b r_*(b)^{-1-\alpha_b}\frac{\alpha_b}{\alpha_b+\xi-1}(r_*(b)-\rho)H(W)$$

where

$$H(W) \;=\; F^{-1}\sum_f (w_f^*)^2\,.$$

Thus,

$$\begin{aligned}
r_f^{(2)}(b) &= \frac{w_f^*\alpha_b}{\alpha_b+\xi-1}\Big(r_f^{(1)}(b) - \Big(r_f^{(1)}(b)r_*(b)^{-1}\alpha_b - \alpha_b r_*(b)^{-1}\frac{\alpha_b}{\alpha_b+\xi-1}(r_*(b)-\rho)H(W)\Big)(r_*(b)-\rho)\Big) \\
&= \frac{w_f^*\alpha_b}{\alpha_b+\xi-1}\Big(r_f^{(1)}(b) - \alpha_b r_*(b)^{-1}\Big(r_f^{(1)}(b) - \frac{\alpha_b}{\alpha_b+\xi-1}(r_*(b)-\rho)H(W)\Big)(r_*(b)-\rho)\Big) \\
&= \frac{w_f^*\alpha_b}{\alpha_b+\xi-1}\Big(\frac{w_f^*\alpha_b}{\alpha_b+\xi-1} - \alpha_b r_*(b)^{-1}\Big(\frac{w_f^*\alpha_b}{\alpha_b+\xi-1}(r_*(b)-\rho) - \frac{\alpha_b}{\alpha_b+\xi-1}(r_*(b)-\rho)H(W)\Big)\Big)(r_*(b)-\rho)
\end{aligned}$$

Q.E.D.

By (6), the total payoff that the fund receives from its T-bill/RRP investments is given by

$$\begin{aligned}
D_f^T(\rho)\rho \ + \ (\Delta_f - D_f^T(\rho))\rho_* \ &= \ D_f^T(\rho)(\rho-\rho_*) \ + \ \Delta_f\rho_* \\
&= \ \Big((a_*(f)+\lambda_*(f)(\rho-\rho_*))(\rho-\rho_*) \ + \ \rho_*\Big)\Delta_f \\
&= \ \widetilde{\rho}\,\Delta_f\,,
\end{aligned} \tag{17}$$

where we have defined

$$\widetilde{\rho} \ \equiv \ \Big((a_*(f)+\lambda_*(f)(\rho-\rho_*))(\rho-\rho_*) \ + \ \rho_*\Big)$$

to be the *effective rate* that the fund f earns on its investments across T-bills and RRP.

In equilibrium, the T-bill rate ρ in (17) is the market clearing rate $\hat{\rho}$ satisfying (8). As discussed above, we assume that the fund takes the repo rates charged by competitors as given and optimizes

$$\sum_b \frac{r_f(b)^{1-\alpha_b-\xi} - \widetilde{\rho} r_f(b)^{-\alpha_b-\xi}}{r_f(b)^{-\alpha_b}w_f \ + \ F_{-f}(b)} \ + \ \widetilde{\rho} d_f\,,$$

where $\hat{\rho}$ depends on $(r_f(b))_{b=1}^B$ directly through (8). Define

$$\begin{aligned}
U_{-f} \ &= \ S - a - \sum_{\phi\neq f} a_*(\phi)\Delta_\phi(r_\phi) \\
V_{-f} \ &= \ \lambda + \sum_{\phi\neq f}\lambda_*(\phi)\Delta_\phi(r_\phi)
\end{aligned}$$

to be the two components of the *residual demand* of all other MMFs, defining the level and slope of their demand, as driven by their demand functions (6). The following is true.

Proposition B.2 (Pass-through of repo rates into treasuries) *Suppose that F is large and $d_f = O(w_f)$, and that fund f takes $r_\phi, \phi \neq f$, as given. Let also*

$$\Xi_{-f} \;=\; \left(\frac{a_*(f)}{V_{-f}+\lambda_*(f)d_f} \;+\; \frac{U_{-f}-a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^2}\right).$$

Then,

$$\frac{\partial\hat\rho}{\partial r_f(u)} \;=\; \hat\rho^{(1)}_{r_f(u)}F^{-1} \;+\; \hat\rho^{(2)}_{r_f(u)}F^{-2} \;+\; O(F^{-3}),$$

where

$$\hat\rho^{(1)}_{r_f(u)} \;=\; -\Xi_{-f}w_f^*R_*^\xi(\xi+\alpha_u)r_*(u)^{-\xi-1}$$

$$\hat\rho^{(2)}_{r_f(u)} \;=\Xi_{-f}w_f^*R_*^\xi r_*(u)^{-\xi-1}\left((\xi+\alpha_u)\Big((\xi+\alpha_u+1)r_*(u)^{-1}r_f^{(1)}+r_*(u)^{\alpha_u}\Gamma_*(u)^{(1)}\Big) \;+\; \alpha_u w_f^*\right) \;-\; Q_f^*(u)$$

where we have defined

$$Q_f^*(u) \;=\; 2(w_f^*)^2F^{-2}\frac{U_{-f}-a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3}\Big(\sum_b(R_*/r_*(b))^\xi\Big)\left(R_*^\xi(\xi+\alpha_u)r_*(u)^{-\xi-1}\right)$$

and where

$$\Gamma_*(b)^{(1)} \;=\; -\alpha_b r_*(b)^{-1-\alpha_b}E[r_f^{(1)}(b)]\,, \tag{18}$$

and where $r_f^{(1)}(b)$ is to be determined later in general equilibrium.

By (6), the total payoff that the fund receives from its T-bill/RRP investments is given by

$$\begin{aligned}
&D_f^T(\rho)\rho \;+\; (\Delta_f - D_f^T(\rho))\rho_* \;=\; D_f^T(\rho)(\rho-\rho_*) \;+\; \Delta_f\rho_*\\
&=\; \Big((a_*(f)+\lambda_*(f)(\rho-\rho_*))(\rho-\rho_*) \;+\; \rho_*\Big)\Delta_f\\
&=\; \widetilde\rho\,\Delta_f\,,
\end{aligned}$$

where we have defined

$$\widetilde{\rho} \;\equiv\; \Big((a_*(f)+\lambda_*(f)(\rho-\rho_*))(\rho-\rho_*) \;+\; \rho_*\Big)$$

to be the *effective rate* that the fund f earns on its investments across T-bills and RRP.

Proof of Proposition B.2. We have

$$\begin{aligned}
\hat{\rho} \;&=\; \rho_* \;+\; \frac{U_{-f}-a_*(f)\Delta_f((R(b))_{b\in B})}{V_{-f}+\lambda_*(f)\Delta_f((R(b))_{b\in B})}\\
&=\; \rho_* \;+\; \frac{U_{-f}-a_*(f)\left(d_f-\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\right)}{V_{-f}+\lambda_*(f)\left(d_f-\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\right)}\\
&=\; \rho_* \;+\; \frac{U_{-f}-a_*(f)\left(d_f-\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\right)}{V_{-f}+\lambda_*(f)d_f}\\
&\times\left(1+\frac{1}{V_{-f}+\lambda_*(f)d_f}\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}+\Big(\frac{1}{V_{-f}+\lambda_*(f)d_f}\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\Big)^2\right) \;+\; O(F^{-3})\\
&=\; \rho_* \;+\; \frac{U_{-f}-a_*(f)d_f}{V_{-f}+\lambda_*(f)d_f}\\
&+\; \left(\frac{a_*(f)}{V_{-f}+\lambda_*(f)d_f} \;+\; \frac{U_{-f}-a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^2}\right)\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\\
&+\frac{U_{-f}-a_*(f)d_f}{V_{-f}+\lambda_*(f)d_f}\Big(\frac{1}{V_{-f}+\lambda_*(f)d_f}\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\Big)^2+\; O(F^{-3})\\
&=\; \rho_* \;+\; \frac{U_{-f}-a_*(f)d_f}{V_{-f}+\lambda_*(f)d_f}\\
&+\; \Xi_{-f}\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}+\frac{U_{-f}-a_*(f)d_f}{V_{-f}+\lambda_*(f)d_f}\Big(\frac{1}{V_{-f}+\lambda_*(f)d_f}\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\Big)^2+\; O(F^{-3})
\end{aligned}$$

where we have defined

$$\Xi_{-f} \;=\; \left(\frac{a_*(f)}{V_{-f}+\lambda_*(f)d_f} \;+\; \frac{U_{-f}-a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^2}\right)\,.$$

Therefore,

$$
\begin{aligned}
&\frac{\partial\hat{\rho}}{\partial r_f(u)}\\
&= \ \Xi_{-f} w_f \left(R_*^\xi \frac{-(\xi+\alpha_u) r_f(u)^{-\xi-\alpha_u-1}\Gamma_*(u) + \alpha_u w_f r_f(u)^{-\alpha_u-1} r_f(u)^{-\xi-\alpha_u}}{\Gamma_*(u)^2} \right)\\
&+ 2w_f^2 \frac{U_{-f} - a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3} \Big(\sum_b (R_*/r_*(b))^\xi \Big) \left(R_*^\xi \frac{-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1}\Gamma_*(u)}{\Gamma_*(u)^2} \right) + \ O(F^{-3})\\
&= \ \Xi_{-f} w_f R_*^\xi \Big(-(\xi+\alpha_u) r_f(u)^{-\xi-\alpha_u-1}\Gamma_*(u)^{-1} + \alpha_u w_f r_*(u)^{-\alpha_u-1} r_*(u)^{-\xi-\alpha_u}\Gamma_*(u)^{-2} \Big)\\
&+ 2w_f^2 \frac{U_{-f} - a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3} \Big(\sum_b (R_*/r_*(b))^\xi \Big) \left(R_*^\xi \frac{-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1}\Gamma_*(u)}{\Gamma_*(u)^2} \right) + \ O(F^{-3})\\
&= \ \Xi_{-f} w_f^* F^{-1} R_*^\xi \Big(-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1}(1-(\xi+\alpha_u+1) r_*(u)^{-1} r_f^{(1)} F^{-1}) r_*(u)^{\alpha_u}(1 - r_*(u)^{\alpha_u}\Gamma_*(u)^{(1)}F^{-1})\\
&+ \alpha_u w_f^* F^{-1} r_*(u)^{-\alpha_u-1} r_*(u)^{-\xi-\alpha_u} r_*(u)^{2\alpha_u} \Big)\\
&+ 2(w_f^*)^2 F^{-2} \frac{U_{-f} - a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3} \Big(\sum_b (R_*/r_*(b))^\xi \Big) \left(R_*^\xi \frac{-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1}\Gamma_*(u)}{\Gamma_*(u)^2} \right) + \ O(F^{-3})\\
&= \ -\Xi_{-f} w_f^* F^{-1} R_*^\xi (\xi+\alpha_u) r_*(u)^{-\xi-1}\\
&+ \ \Xi_{-f} w_f^* F^{-2} R_*^\xi r_*(u)^{-\xi-1} \Big((\xi+\alpha_u)\Big((\xi+\alpha_u+1) r_*(u)^{-1} r_f^{(1)} + r_*(u)^{\alpha_u}\Gamma_*(u)^{(1)} \Big) \ + \ \alpha_u w_f^* \Big) - \ Q_f^*(u) F^{-2}
\end{aligned}
\tag{19}
$$

where we have defined

$$
Q_f^*(u) \ = \ 2(w_f^*)^2 F^{-2} \frac{U_{-f} - a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3} \Big(\sum_b (R_*/r_*(b))^\xi \Big) \Big(R_*^\xi (\xi+\alpha_u) r_*(u)^{-\xi-1} \Big)
$$

Thus,

$$
\frac{\partial\hat{\rho}}{\partial r_f(u)} \ = \ \hat{\rho}^{(1)}_{r_f(u)} F^{-1} \ + \ \hat{\rho}^{(2)}_{r_f(u)} F^{-2} \ + \ O(F^{-3}), \tag{20}
$$

where, using that

$$
\Gamma_*(b) \ = \ r_*(b)^{-\alpha_b} \ + \ \Gamma_*(b)^{(1)} F^{-1},
$$

with

$$\Gamma_*(b)^{(1)} \;=\; -\alpha_b r_*(b)^{-1-\alpha_b} E[r_f^{(1)}(b)]\,, \tag{21}$$

and *where* $r_f^{(1)}(b)$ *is to be determined later in general equilibrium.* Q.E.D.

Recall that

$$D_f^T(\rho) \;=\; (a_*(f) + \lambda_*(f)(\rho - \rho_*))\Delta_f$$

is the demand for T-bills by the fund f, and let

$$\widetilde{\rho}_f \;=\; \underbrace{\rho_*}_{RRP\ rate} \;+\; \frac{D_f^T(\rho)}{\Delta_f} \underbrace{(\hat{\rho}(r_f) - \rho_*)}_{excess\ return\ on\ the\ T-bills}$$

be the effective rate earned by the fund f on its residual cash Δ_f. Let also

$$\Delta_f^* \;=\; \frac{\Delta_f}{w_f}$$

be the ratio of the residual cash to fund size in the repo market. Let also

$$\Lambda_f \;=\; \frac{(\xi + \alpha_u)R_*^{\xi}}{\xi + \alpha_u - 1} \Xi_{-f} \left(2\frac{D_f^T(\hat{\rho})}{\Delta_f} - a_*(f) \right)$$

be a measure of funds' own price impact in the T-bill market. We will also use $E[x_f]$ to denote cross-sectional averages, weighted with w_f^* :

$$E[x_f] \;=\; F^{-1} \sum_f w_f^* x_f\,.$$

Proposition B.3 (Equilibrium Repo Markups) *The optimal repo rate set by fund f for bank b satisfies*

$$r_f(u) \;=\; \frac{\alpha_u + \xi}{\alpha_u + \xi - 1} \widetilde{\rho}_f \;+\; F^{-1} r_f(u)^{(1)} \;+\; F^{-2} r_f(u)^{(2)} \;+\; O(F^{-2})$$

with

$$r_f(u)^{(1)} \;=\; \underbrace{\frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\left(1+\frac{\alpha_u w_f^*}{\alpha_u+\xi-1}F^{-1}\right)(r_*(u)-\widetilde{\rho}_f)}_{repo\ market\ power} \;-\; \underbrace{w_f^*\Lambda_f\Delta_f^*}_{T-bill\ price\ impact}$$

and

$$\begin{aligned} r_f(u)^{(2)} \;&=\; \underbrace{(w_f^*)^2 C_f(u)}_{convexity\ price\ impact\ adjustment} \\ &+\; \frac{\alpha_u^2 w_f^* r_*(u)^{-1}}{\alpha_u+\xi-1}(r_*(u)-\widetilde{\rho}_f)\underbrace{(E[r_f(u)^{(1)}]-r_f(u)^{(1)})}_{heterogeneity} \end{aligned}$$

where

$$\begin{aligned} C_f(u) \;&=\; -2((\alpha_u+\xi-1))^{-1}r_*(u)^{\xi+1}\Delta_f^*\frac{U_{-f}-a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3}\Big(\sum_b (R_*/r_*(b))^{\xi}\Big)\left(R_*^{\xi}(\xi+\alpha_u)r_*(u)^{-\xi-1}\right) \\ &+\; (\alpha_u+\xi-1))^{-1}\Delta_f^*\Xi_{-f}R_*^{\xi}\alpha_u \end{aligned}$$

is a convexity adjustment for the price-impact effects.

Proof of Proposition B.3. The first order condition with respect to a particular bank u is

$$\begin{aligned} 0 \;&=\; \frac{\partial}{\partial r_f(u)}\sum_b \frac{r_f(b)^{1-\alpha_b-\xi}-\widetilde{\rho}_f r_f(b)^{-\alpha_b-\xi}}{r_f(b)^{-\alpha_b}w_f \;+\; F_{-f}(b)} + \frac{\partial}{\partial r_f(u)}\widetilde{\rho}_f d_f/w_f \\ &= \Big(((1-\alpha_u-\xi)r_f(u)^{-\alpha_u-\xi}+(\alpha_u+\xi)\widetilde{\rho}_f r_f(u)^{-\alpha_u-\xi-1})(r_f(u)^{-\alpha_u}w_f \;+\; F_{-f}(u)) \\ &+ \alpha_u r_f(u)^{-\alpha_u-1}w_f(r_f(u)^{1-\alpha_u-\xi}-\widetilde{\rho}_f r_f(u)^{-\alpha_u-\xi})\Big)\Big(r_f(u)^{-\alpha_u}w_f \;+\; F_{-f}(u)\Big)^{-2} \\ &+ \frac{\partial\widetilde{\rho}_f}{\partial r_f(u)}w_f^{-1}\Delta_f \end{aligned}$$

where we have defined

$$\widetilde{\rho}_f \;=\; \Big((\hat{\rho}(r_f)-\rho_*)(a_*(f)+\lambda_*(f)(\hat{\rho}(r_f)-\rho_*))+\rho_*\Big)$$

to be the effective T-bill rate. Now, by (19), we have

$$
\begin{aligned}
&\frac{\partial}{\partial r_f(u)}\widetilde{\rho}_f \\
&= \frac{\partial}{\partial r_f(u)}\Big((\hat{\rho}(r_f)-\rho_*)(a_*(f)+\lambda_*(f)(\hat{\rho}(r_f)-\rho_*))+\rho_*\Big) \\
&= \frac{\partial\hat{\rho}_u}{\partial r_f(u)}(a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*))\,.
\end{aligned}
$$

Thus,

$$
\begin{aligned}
0 \;=\; &\Big(((1-\alpha_u-\xi)r_f(u)^{-\alpha_u-\xi}+(\alpha_u+\xi)\widetilde{\rho}_f r_f(u)^{-\alpha_u-\xi-1})\Gamma_*(b) \\
&+\alpha_u r_f(u)^{-\alpha_u-1}w_f(r_f(u)^{1-\alpha_u-\xi}-\widetilde{\rho}_f r_f(u)^{-\alpha_u-\xi})\Big) \\
&+\;\Gamma_*(b)^2\frac{\partial\widetilde{\rho}_f}{\partial r_f(u)}\Delta(f)w_f^{-1}\;+\;O(F^{-3})\,.
\end{aligned}
$$

Diving this identity by $r_f(u)^{-\alpha_u-\xi-1}(\alpha_u+\xi-1)\Gamma_*(b)$, we get

$$
\begin{aligned}
0 \;=\; &O(F^{-3})\;+\;\Big((-r_f(u)+\frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f)) \\
&+\alpha_u r_f(u)^{-\alpha_u-1}w_f(r_f(u)^{1-\alpha_u-\xi}-\widetilde{\rho}_f r_f(u)^{-\alpha_u-\xi})(\alpha_u+\xi-1)^{-1}\Gamma_*(u)^{-1}r_f(u)^{\alpha_u+\xi+1}\Big) \\
&(r_f(u)^{-\alpha_u-\xi-1}(\alpha_u+\xi-1)\Gamma_*(b))^{-1}\frac{\partial\widetilde{\rho}_f}{\partial r_f(u)}\Gamma_*(b)^2 w_f^{-1}\Delta_f
\end{aligned}
$$

so that, using (19) and (20), we get

$$
\begin{aligned}
r_f(u) \;=\;& \frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f \\
+\;& \frac{\alpha_u}{\alpha_u+\xi-1}\frac{r_f(u)^{-\alpha_u}w_f(r_f(u)-\widetilde{\rho}_f)}{\Gamma_*(u)} \\
+\;& (r_f(u)^{-\alpha_u-\xi-1}(\alpha_u+\xi-1))^{-1}\frac{\partial\widetilde{\rho}_f}{\partial r_f(u)}\Gamma_*(b)w_f^{-1}\Delta_f \;+\; O(F^{-3}) \\
=\;& \frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f \\
+\;& \frac{\alpha_u}{\alpha_u+\xi-1}\frac{w_f(r_f(u)^{1-\alpha_u}-r_f(u)^{-\alpha_u}\widetilde{\rho}_f)}{\Gamma_*(u)} \\
+\;& (r_f(u)^{-\alpha_u-\xi-1}(\alpha_u+\xi-1))^{-1}\frac{\partial\widetilde{\rho}_f}{\partial r_f(u)}\Gamma_*(b)w_f^{-1}\Delta_f \;+\; O(F^{-3}) \\
=\;& \frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f \\
+\;& \frac{\alpha_u}{\alpha_u+\xi-1}\frac{w_f\Big(r_*(u)^{1-\alpha_u}(1+(1-\alpha_u)r_*(u)^{-1}r_f^{(1)}(u)F^{-1})-r_*(u)^{-\alpha_u}(1-\alpha_u r_*(u)^{-1}r_f^{(1)}(u)F^{-1})\widetilde{\rho}_f\Big)}{r_*(u)^{-\alpha_u}\;+\;\Gamma_*(u)^{(1)}F^{-1}} \\
+\;& ((\alpha_u+\xi-1))^{-1}r_*(u)^{\alpha_u+\xi+1}\big(1+(\alpha_u+\xi+1)r_*(u)^{-1}r_f^{(1)}(u)F^{-1}\big) \\
\times\;& \Big(\hat{\rho}^{(1)}_{r_f(u)}F^{-1}\;+\;\hat{\rho}^{(2)}_{r_f(u)}F^{-2}\Big)(a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*)) \\
\times\;& (r_*(u)^{-\alpha_u}\;+\;\Gamma_*(u)^{(1)}F^{-1})w_f^{-1}\Delta_f\;+\;O(F^{-3}) \\
=\;& \frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f \\
+\;& \frac{\alpha_u w_f}{\alpha_u+\xi-1}\Big((r_*(u)^{1-\alpha_u}-r_*(u)^{-\alpha_u}\widetilde{\rho}_f)+\;((1-\alpha_u)r_*(u)^{-\alpha_u}+\alpha_u r_*(u)^{-\alpha_u-1}\widetilde{\rho}_f)r_f^{(1)}(u)F^{-1}\Big) \\
\times\;& r_*(u)^{\alpha_u}(r_*(u)^{\alpha_u}\;-\;r_*(u)^{\alpha_u}\Gamma_*(u)^{(1)}F^{-1}) \\
+\;& ((\alpha_u+\xi-1))^{-1}r_*(u)^{\alpha_u+\xi+1}\big(1+(\alpha_u+\xi+1)r_*(u)^{-1}r_f^{(1)}(u)F^{-1}\big) \\
\times\;& F^{-1}\Big(\hat{\rho}^{(1)}_{r_f(u)}\;+\;\hat{\rho}^{(2)}_{r_f(u)}F^{-1}\Big)(a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*)) \\
\times\;& (r_*(u)^{-\alpha_u}\;+\;\Gamma_*(u)^{(1)}F^{-1})w_f^{-1}\Delta_f\;+\;O(F^{-3})
\end{aligned}
$$

Thus,

$$
\begin{aligned}
& r_f(u)^{(1)} \\
= \; & \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\frac{r_*(u)^{1-\alpha_u}-r_*(u)^{-\alpha_u}\widetilde{\rho}_f}{r_*(u)^{-\alpha_u}} \\
+ \; & ((\alpha_u+\xi-1))^{-1} r_*(u)^{\alpha_u+\xi+1}\hat{\rho}^{(1)}_{r_f(u)} r_*(u)^{-\alpha_u} w_f^{-1}\Delta_f \\
= \; & \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}(r_*(u)-\widetilde{\rho}_f) \\
- \; & ((\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1}\Big(w_f^*\Xi_{-f}\left(R_*^{\xi}\frac{(\xi+\alpha_u)r_*(u)^{-\xi-\alpha_u-1}}{r_*(u)^{-\alpha_u}}\right)\Big)\Delta_f^*(a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*)) \\
= \; & \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}(r_*(u)-\widetilde{\rho}_f)-\frac{\xi+\alpha_u}{\xi+\alpha_u-1}w_f^*\Xi_{-f}R_*^{\xi}\Delta_f^*(a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*))
\end{aligned}
$$

Hence, by (21), we have

$$\Gamma_*(b)^{(1)} \;=\; -\alpha_b r_*(b)^{-1-\alpha_b}E[r_f^{(1)}(b)]\,.$$

Furthermore, defining

$$\Delta_f^* \;=\; \Delta_f/w_f,$$

we get

$$
\begin{aligned}
& r_f(u)^{(2)} \\
& = \ \hat\rho^{(2)}_{r_f(u)}((\alpha_u+\xi-1))^{-1} r_*(u)^{\alpha_u+\xi+1} r_*(u)^{-\alpha_u}\Delta^*_f(a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*)) \\
& + \ \frac{\alpha_u w_f}{\alpha_u+\xi-1}\Big(-(r_*(u)^{1-\alpha_u} - r_*(u)^{-\alpha_u}\widetilde\rho_f) r_*(u)^{2\alpha_u}\Gamma_*(u)^{(1)} \\
& + \ ((1-\alpha_u) r_*(u)^{-\alpha_u} + \alpha_u r_*(u)^{-\alpha_u-1}\widetilde\rho_f) r^{(1)}_f(u) r_*(u)^{\alpha_u}\Big) \\
& + \ ((\alpha_u+\xi-1))^{-1} r_*(u)^{\alpha_u+\xi+1}\hat\rho^{(1)}_{r_f(u)}\Big((\alpha_u+\xi+1) r_*(u)^{-1} r^{(1)}_f(u) r_*(u)^{-\alpha_u} \ + \ \Gamma_*(u)^{(1)}\Big) \\
& \times \Delta^*_f(a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*)) \\
& = \ ((\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1}\Delta^*_f \\
& \times \left(\Xi_{-f} w^*_f R^\xi_* r_*(u)^{-\xi-1}\left((\xi+\alpha_u)\Big((\xi+\alpha_u+1) r_*(u)^{-1} r^{(1)}_f + r_*(u)^{\alpha_u}\Gamma_*(u)^{(1)}\Big) \ + \ \alpha_u w^*_f\right) - \ Q^*_f(u)\right) \\
& \times (a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*)) \\
& + \ \frac{\alpha_u w^*_f}{\alpha_u+\xi-1}\Big(-(r_*(u)^{1-\alpha_u} - r_*(u)^{-\alpha_u}\widetilde\rho_f) r_*(u)^{2\alpha_u}\Gamma_*(u)^{(1)} \\
& + \ ((1-\alpha_u) r_*(u)^{-\alpha_u} + \alpha_u r_*(u)^{-\alpha_u-1}\widetilde\rho_f) r^{(1)}_f(u) r_*(u)^{\alpha_u}\Big) \\
& + \ ((\alpha_u+\xi-1))^{-1} r_*(u)^{\alpha_u+\xi+1} \\
& \times \Big(-\Xi_{-f} w^*_f R^\xi_*(\xi+\alpha_u) r_*(u)^{-\xi-1}\Big)\Big((\alpha_u+\xi+1) r_*(u)^{-1} r^{(1)}_f(u) r_*(u)^{-\alpha_u} \ + \ \Gamma_*(u)^{(1)}\Big) \\
& \times \Delta^*_f(a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*)) \\
& = \ -((\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1}\Delta^*_f Q^*_f(u) \ + \ (\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1}\Delta^*_f\Xi_{-f} w^*_f R^\xi_* r_*(u)^{-\xi-1}\alpha_u w^*_f \\
& + \ \Omega_1 r^{(1)}_f \ + \ \Omega_2\Gamma_*(u)^{(1)} \,.
\end{aligned}
$$

Here, we have defined

$$
\begin{aligned}
\Omega_1 \;&=\; ((\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1}\Delta_f^* \\
&\times \left(\Xi_{-f} w_f^* R_*^{\xi} r_*(u)^{-\xi-1}\left((\xi+\alpha_u)\Big((\xi+\alpha_u+1) r_*(u)^{-1}\Big)\right)\right) \\
&\times (a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*)) \\
&+\; \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\Big(((1-\alpha_u) r_*(u)^{-\alpha_u}+\alpha_u r_*(u)^{-\alpha_u-1}\widetilde{\rho}_f) r_*(u)^{\alpha_u}\Big) \\
&+\; ((\alpha_u+\xi-1))^{-1} r_*(u)^{\alpha_u+\xi+1} \\
&\times \Big(-\Xi_{-f} w_f^* R_*^{\xi}(\xi+\alpha_u) r_*(u)^{-\xi-1}\Big)\Big((\alpha_u+\xi+1) r_*(u)^{-1} r_*(u)^{-\alpha_u}\Big)\Delta_f^*(a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*)) \\
&=\; \Xi_{-f} w_f^* \Delta_f^*(a_*(f)+2\lambda_*(f)(\hat{\rho}(r_f)-\rho_*)) R_*^{\xi} r_*(u)^{-1}\Bigg(((\alpha_u+\xi-1))^{-1}\Bigg(\\
&\left((\xi+\alpha_u)\Big((\xi+\alpha_u+1)\Big)\right)\Bigg) \\
&+\; ((\alpha_u+\xi-1))^{-1} \\
&\times \Big(-(\xi+\alpha_u)\Big)\Big((\alpha_u+\xi+1)\Big)\Bigg) \\
&+\; \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\Big(((1-\alpha_u) r_*(u)^{-\alpha_u}+\alpha_u r_*(u)^{-\alpha_u-1}\widetilde{\rho}_f) r_*(u)^{\alpha_u}\Big) \\
&=\; \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\Big(((1-\alpha_u) r_*(u)^{-\alpha_u}+\alpha_u r_*(u)^{-\alpha_u-1}\widetilde{\rho}_f) r_*(u)^{\alpha_u}\Big)
\end{aligned}
$$

and

$$
\begin{aligned}
\Omega_2 \;&=\; ((\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1}\Delta_f^*\\
&\times \left(\Xi_{-f} w_f^* R_*^{\xi} r_*(u)^{-\xi-1}\left((\xi+\alpha_u)\Big(r_*(u)^{\alpha_u}\Big)\right)\right)\\
&\times (a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*))\\
&+\;\frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\Big(-(r_*(u)^{1-\alpha_u}-r_*(u)^{-\alpha_u}\widetilde{\rho}_f)r_*(u)^{2\alpha_u}\Big)\\
&+\;((\alpha_u+\xi-1))^{-1} r_*(u)^{\alpha_u+\xi+1}\\
&\times \Big(-\Xi_{-f} w_f^* R_*^{\xi}(\xi+\alpha_u) r_*(u)^{-\xi-1}\Big)\\
&\times \Delta_f^*(a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*))\\
&=\;\Delta_f^*(a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*))\left(((\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1}\left(\Xi_{-f} w_f^* R_*^{\xi} r_*(u)^{-\xi-1}\left((\xi+\alpha_u)\Big(r_*(u)^{\alpha_u}\Big)\right)\right)\right.\\
&+((\alpha_u+\xi-1))^{-1} r_*(u)^{\alpha_u+\xi+1}\\
&\left.\times \Big(-\Xi_{-f} w_f^* R_*^{\xi}(\xi+\alpha_u) r_*(u)^{-\xi-1}\Big)\right)\\
&+\;\frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\Big(-(r_*(u)^{1-\alpha_u}-r_*(u)^{-\alpha_u}\widetilde{\rho}_f)r_*(u)^{2\alpha_u}\Big)\\
&=\;\frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\Big(-(r_*(u)^{1}-\widetilde{\rho}_f)r_*(u)^{\alpha_u}\Big)\,.
\end{aligned}
$$

Summarizing, we get

$$
r_f(u) \;=\; \frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f \;+\; F^{-1} r_f(u)^{(1)} \;+\; F^{-2} r_f(u)^{(2)} \;+\; O(F^{-2})
$$

with

$$
r_f(u)^{(1)} \;=\; \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}(r_*(u)-\widetilde{\rho}_f) - \frac{\xi+\alpha_u}{\xi+\alpha_u-1} w_f^* \Xi_{-f} R_*^{\xi}\Delta_f^*(a_*(f)+2\lambda_*(f)(\hat\rho(r_f)-\rho_*))
$$

and

$$
\Gamma_*(b)^{(1)} \;=\; -\alpha_b r_*(b)^{-1-\alpha_b} E[r_f^{(1)}(b)]
$$

and

$$
\begin{aligned}
& r_f(u)^{(2)} \\
& = \; -((\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1} \Delta_f^* Q_f^*(u) \; + \; (\alpha_u+\xi-1))^{-1} r_*(u)^{\xi+1} \Delta_f^* \Xi_{-f} w_f^* R_*^{\xi} r_*(u)^{-\xi-1} \alpha_u w_f^* \\
& + \; \Omega_1 r_f^{(1)} \; + \; \Omega_2 \Gamma_*(u)^{(1)} \,.
\end{aligned}
$$

Q.E.D.

In the presence of market power and imperfect competition in both repo and T-bill markets, equilibrium T-bill rate, $\hat{\rho}$, deviates from its frictionless level (10). To characterize this deviation, we introduce an important quantity,

$$
\psi_f \;=\; (\alpha+\xi) r_*(f)^{-\xi-1} R_*^{\xi} (\lambda+\bar{\lambda})^{-1} \Big(\underbrace{a_f}_{inelastic} + (S-a-A)(\lambda+\bar{\lambda})^{-1} \underbrace{\lambda_f}_{elastic} \Big) \,,
$$

capturing the total pass-through of residual cash flow shocks of fund f into the fund's demand for T-bills. We then define

$$
\mathcal{E} \;=\; 1 \;+\; 2(\hat{\rho}^* - \rho_*) \frac{\alpha+\xi}{\alpha+\xi-1} \Big(\frac{\xi}{\alpha+\xi} E[\psi_f] E[\lambda_*(f)] \;+\; \mathrm{Cov}(\psi_f, \lambda_*(f)) \Big)
$$

This quantity is the equilibrium elasticity of the T-bill rate to shocks originating from imperfect competition. The following is true.

Proposition B.4 (Equilibrium T-bill rate) *In equilibrium,*

$$
\hat{\rho} \;=\; \hat{\rho}^* \;+\; \hat{\rho}^{(1)} F^{-1} \;+\; O(F^{-2}) \,,
$$

where

$$\hat{\rho}^{(1)}$$

$$= -\mathcal{E}^{-1}\Bigg(\frac{\xi}{(\alpha+\xi)}\underbrace{E[\psi_f]}_{average\ passthrough}\Big(\frac{\alpha}{\alpha+\xi-1}(r_*(f)-\widetilde{\rho}_f^*)\underbrace{H(W)}_{repo\ concentration} - \underbrace{E[w_f^*\Lambda_f\Delta_f^*]}_{price\ impact\ internalization}\Big)$$

$$+\underbrace{\mathrm{Cov}\Big(\psi_f, \frac{\alpha w_f^*}{\alpha+\xi-1}(r_*(f)-\widetilde{\rho}_f^*)\ -\ w_f^*\Lambda_f\Delta_f^*\Big)}_{strategic\ interactions\ in\ the\ T-bill\ market}\Bigg)$$

Proof of Proposition B.4. In equilibrium,

$$\hat{\rho}\ =\ \hat{\rho}^*\ +\ \hat{\rho}^{(1)}F^{-1}\ +\ \hat{\rho}^{(2)}F^{-2}\ +\ O(F^{-3})\,,$$

where

$$\hat{\rho}^*\ =\ \rho_*\ +\ \frac{S-a-\sum_f a_*(f)\Delta_f(0)}{\lambda+\sum_f\lambda_*(f)\Delta(0)}$$

is the level of rates absent market power, where

$$\Delta_f(0)\ =\ \left(d_f-\sum_b(R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\right).$$

Similarly,

$$\widetilde{\rho}_f\ =\ \widetilde{\rho}_f^*\ +\ \widetilde{\rho}_f^{(1)}F^{-1}\ +\ \widetilde{\rho}_f^{(2)}F^{-1}\ +\ O(F^{-3})$$

where

$$\widetilde{\rho}_f^*\ =\ \Big((\hat{\rho}^*-\rho_*)(a_*(f)+\lambda_*(f)(\hat{\rho}^*-\rho_*))+\rho_*\Big)$$

and

$$
\begin{aligned}
\widetilde{\rho}_f \;&=\; \Big((\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)(a_*(f) + \lambda_*(f)(\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)) + \rho_* \Big) \\
&=\; \rho_* \;+\; (\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)a_*(f) \\
&+\; (\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)^2\lambda_*(f) \\
&=\; \rho_* \;+\; (\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)a_*(f) \\
&+\; \Big((\hat{\rho}^* - \rho_*)^2 \;+\; 2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(1)}F^{-1} \;+\; 2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(2)}F^{-2} + (\hat{\rho}^{(1)})^2F^{-2} \Big)\lambda_*(f) \\
&=\; \widetilde{\rho}_f^* \;+\; 2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(1)}\lambda_*(f)F^{-1} \;+\; (2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(2)} + (\hat{\rho}^{(1)})^2)\lambda_*(f)F^{-2} \;+\; O(F^{-3})
\end{aligned}
\tag{22}
$$

Therefore,

$$\sum_f a_*(f)\Delta_f \;=\; E[a_f d_f^*] - \sum_b E\left[a_f (R_*/r_f(b))^\xi \frac{r_f(b)^{-\alpha_b}}{\Gamma_*(b)}\right]$$

$$= \; E[a_f d_f^*] - \sum_b E\Bigg[a_f R_*^\xi$$

$$\times \; \frac{r_*(b)^{-\alpha_b-\xi} - (\alpha_b+\xi) r_*(b)^{-\alpha_b-\xi-1}(r_f(b)^{(1)}F^{-1} + r_f(b)^{(2)}F^{-2}) + 0.5(\alpha_b+\xi)(\alpha_b+\xi+1)(r_f(b)^{(1)})^2 F^{-2}}{r_*(b)^{-\alpha_b} + \Gamma_*(b)^{(1)}F^{-1} + \Gamma_*(b)^{(2)}F^{-2}}\Bigg]$$

$$= \; E[a_f d_f^*] - \sum_b E\Bigg[a_f R_*^\xi$$

$$\times \Bigg(r_*(b)^{-\alpha_b-\xi} - (\alpha_b+\xi) r_*(b)^{-\alpha_b-\xi-1}(r_f(b)^{(1)}F^{-1} + r_f(b)^{(2)}F^{-2})$$

$$+ 0.5(\alpha_b+\xi)(\alpha_b+\xi+1) r_*(b)^{-\alpha_b-\xi-1}(r_f(b)^{(1)})^2 F^{-2}\Bigg)$$

$$\times\, r_*(b)^{\alpha_b}\Bigg(1 - r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)}F^{-1} - r_*(b)^{\alpha_b}\Gamma_*(b)^{(2)}F^{-2} + (r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)}F^{-1})^2\Bigg)\Bigg]$$

$$= \; E[a_f d_f^*] - \sum_b E\Bigg[a_f R_*^\xi$$

$$\Bigg(r_*(b)^{-\xi} \;+\; F^{-1}\Big(- r_*(b)^{-\xi} r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)} - (\alpha_b+\xi) r_*(b)^{-\xi-1} r_f(b)^{(1)}\Big)$$

$$+ \; F^{-2}\Big(r_*(b)^{-\xi}(-r_*(b)^{\alpha_b}\Gamma_*(b)^{(2)} + (r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)})^2) + (\alpha_b+\xi) r_*(b)^{-\xi-1} r_f(b)^{(1)} r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)}$$

$$+ 0.5(\alpha_b+\xi)(\alpha_b+\xi+1) r_*(b)^{-\xi-2}(r_f(b)^{(1)})^2 - (\alpha_b+\xi) r_*(b)^{-\xi-1} r_f(b)^{(2)}\Big)\Bigg)\Bigg]$$

By assumption, all banks are identical, and hence we can rewrite it as

$$\sum_f a_*(f)\Delta_f \;=\; A \;+\; (A_{1,1} r_f^{(1)} \;+\; A_{1,2}\Gamma_*^{(1)})F^{-1}$$

$$+ \; (B_{2,0}(r_f^{(1)})^2 \;+\; B_{1,1} r_f^{(1)}\Gamma_*^{(1)} \;+\; B_{0,2}(\Gamma_*^{(1)})^2 + a_1 r_f^{(2)} + a_2\Gamma_*^{(2)})F^{-2} \;+\; O(F^{-3})\,,$$

and similarly

$$\sum_f \lambda_*(f)\Delta_f \;=\; C \;+\; (C_{1,1} r_f^{(1)} \;+\; C_{1,2}\Gamma_*^{(1)})F^{-1}$$

$$+\;(D_{2,0}(r_f^{(1)})^2 \;+\; D_{1,1} r_f^{(1)}\Gamma_*^{(1)} \;+\; D_{0,2}(\Gamma_*^{(1)})^2 + a_1 r_f^{(2)} + a_2\Gamma_*^{(2)})F^{-2} \;+\; O(F^{-3})\,,$$

so that

$$\left(\lambda + \sum_f \lambda_*(f)\Delta_f\right)^{-1} \;=\; \Bigg(\lambda + \bar{\lambda} \;+\; (C_{1,1} r_f^{(1)} \;+\; C_{1,2}\Gamma_*^{(1)})F^{-1}$$

$$+\;(D_{2,0}(r_f^{(1)})^2 \;+\; D_{1,1} r_f^{(1)}\Gamma_*^{(1)} \;+\; D_{0,2}(\Gamma_*^{(1)})^2 + a_1 r_f^{(2)} + a_2\Gamma_*^{(2)})F^{-2} \;+\; O(F^{-3})\Bigg)^{-1}$$

$$=\;(\lambda + \bar{\lambda})^{-1}\Bigg(1 - (\lambda + \bar{\lambda})^{-1}(C_{1,1} r_f^{(1)} \;+\; C_{1,2}\Gamma_*^{(1)})F^{-1}$$

$$-\,(\lambda + \bar{\lambda})^{-1}\Big((D_{2,0}(r_f^{(1)})^2 \;+\; D_{1,1} r_f^{(1)}\Gamma_*^{(1)} \;+\; D_{0,2}(\Gamma_*^{(1)})^2 + a_1 r_f^{(2)} + a_2\Gamma_*^{(2)})F^{-2}\Big)$$

$$+\;(\lambda + \bar{\lambda})^{-2}(C_{1,1} r_f^{(1)} \;+\; C_{1,2}\Gamma_*^{(1)})^2 F^{-2}\Bigg)$$

To solve for $\hat\rho^{(1)}, \hat\rho^{(2)}$ we proceed to solving the market clearing equation

$$
\begin{aligned}
&\hat\rho^* \ + \ \hat\rho^{(1)}F^{-1} \ + \ \hat\rho^{(2)}F^{-1} \ + \ O(F^{-3})\\
&= \hat\rho \ = \ \rho_* \ + \ \frac{S-a-\sum_f a_*(f)\Delta_f}{\lambda+\sum_f \lambda_*(f)\Delta_f}\\
&= \ \rho_* \ + \ \frac{S-a-\sum_f a_*(f)\left(d_f-\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\right)}{\lambda+\sum_f \lambda_*(f)\left(d_f-\sum_b (R_*/r_f(b))^{\xi}\frac{r_f(b)^{-\alpha_b}w_f}{\Gamma_*(b)}\right)}\\
&= \ \Bigg(S-a-A \ - \ (A_{1,1}r_f^{(1)} \ + \ A_{1,2}\Gamma_*^{(1)})F^{-1}\\
&- \ (B_{2,0}(r_f^{(1)})^2 \ + \ B_{1,1}r_f^{(1)}\Gamma_*^{(1)} \ + \ B_{0,2}(\Gamma_*^{(1)})^2+a_1r_f^{(2)}+a_2\Gamma_*^{(2)})F^{-2}\Bigg)\\
&\times(\lambda+\bar\lambda)^{-1}\Bigg(1-(\lambda+\bar\lambda)^{-1}(C_{1,1}r_f^{(1)} \ + \ C_{1,2}\Gamma_*^{(1)})F^{-1}\\
&-(\lambda+\bar\lambda)^{-1}\Big((D_{2,0}(r_f^{(1)})^2 \ + \ D_{1,1}r_f^{(1)}\Gamma_*^{(1)} \ + \ D_{0,2}(\Gamma_*^{(1)})^2+a_1r_f^{(2)}+a_2\Gamma_*^{(2)})F^{-2}\Big)\\
&+ \ (\lambda+\bar\lambda)^{-2}(C_{1,1}r_f^{(1)} \ + \ C_{1,2}\Gamma_*^{(1)})^2F^{-2}\Bigg)\\
&= \ (S-a-A)(\lambda+\bar\lambda)^{-1} \ - \ (\lambda+\bar\lambda)^{-1}(A_{1,1}r_f^{(1)} \ + \ A_{1,2}\Gamma_*^{(1)})F^{-1}\\
&- \ (S-a-A)(\lambda+\bar\lambda)^{-2}(C_{1,1}r_f^{(1)} \ + \ C_{1,2}\Gamma_*^{(1)})F^{-1}\\
&+ \ (\lambda+\bar\lambda)^{-2}(A_{1,1}r_f^{(1)} \ + \ A_{1,2}\Gamma_*^{(1)})(C_{1,1}r_f^{(1)} \ + \ C_{1,2}\Gamma_*^{(1)})F^{-2}\\
&-(S-a-A)(\lambda+\bar\lambda)^{-2}\Big((D_{2,0}(r_f^{(1)})^2 \ + \ D_{1,1}r_f^{(1)}\Gamma_*^{(1)} \ + \ D_{0,2}(\Gamma_*^{(1)})^2+a_1r_f^{(2)}+a_2\Gamma_*^{(2)})F^{-2}\Big)\\
&+ \ (S-a-A)(\lambda+\bar\lambda)^{-2}(C_{1,1}r_f^{(1)} \ + \ C_{1,2}\Gamma_*^{(1)})^2F^{-2}\\
&-(\lambda+\bar\lambda)^{-1}(B_{2,0}(r_f^{(1)})^2 \ + \ B_{1,1}r_f^{(1)}\Gamma_*^{(1)} \ + \ B_{0,2}(\Gamma_*^{(1)})^2+a_1r_f^{(2)}+a_2\Gamma_*^{(2)})F^{-2} \ + \ O(F^{-3})\,.
\end{aligned}
$$

We now summarize these equations for the first-order approximation:

$$\begin{aligned}
\hat{\rho}^{(1)} &= -(\lambda+\bar{\lambda})^{-1}(A_{1,1}r_f^{(1)} \ + \ A_{1,2}\Gamma_*^{(1)}) \\
&- \ (S-a-A)(\lambda+\bar{\lambda})^{-2}(C_{1,1}r_f^{(1)} \ + \ C_{1,2}\Gamma_*^{(1)}) \\
r_f(u)^{(1)} &= \frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f^{(1)} \ + \ \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\left(1+\frac{\alpha_u w_f^*}{\alpha_u+\xi-1}F^{-1}\right)(r_*(u)-\widetilde{\rho}_f) \ - \ w_f^*\Lambda_f\Delta_f^* \\
\widetilde{\rho}_f &= \widetilde{\rho}_f^* \ + \ 2(\hat{\rho}^*-\rho_*)\hat{\rho}^{(1)}\lambda_*(f)F^{-1} \ + \ (2(\hat{\rho}^*-\rho_*)\hat{\rho}^{(2)}+(\hat{\rho}^{(1)})^2)\lambda_*(f)F^{-2} \ + \ O(F^{-3}) \\
\Gamma_*(b)^{(1)} &= -\alpha_b r_*(b)^{-1-\alpha_b}E[r_f^{(1)}(b)] \\
A_{1,1} &= (\alpha+\xi)r_*^{-\xi-1}R_*^{\xi}E[a_f] \\
A_{1,2} &= R_*^{\xi}r_*^{-\xi}r_*^{\alpha}E[a_f] \\
C_{1,1} &= (\alpha+\xi)r_*^{-\xi-1}R_*^{\xi}E[\lambda_f] \\
C_{1,2} &= R_*^{\xi}r_*^{-\xi}r_*^{\alpha}E[\lambda_f]
\end{aligned}$$

where we have used (22) and (18).

Since we assume that all banks are homogeneous, we can omit the dependence on u, b.

Let also

$$\psi_f \ = \ (\alpha+\xi)r_*^{-\xi-1}R_*^{\xi}((\lambda+\bar{\lambda})^{-1}a_f+(S-a-A)(\lambda+\bar{\lambda})^{-2}\lambda_f)$$

Thus, we end up with the first point system

$$\hat{\rho}^{(1)} \ = \ -E\left[\left(\psi_f-\frac{\alpha}{\alpha+\xi}E[\psi_f]\right)\left(\frac{\alpha+\xi}{\alpha+\xi-1}\left(2(\hat{\rho}^*-\rho_*)\hat{\rho}^{(1)}\lambda_*(f)\right) \ + \ \frac{\alpha w_f^*}{\alpha+\xi-1}(r_*-\widetilde{\rho}_f) \ - \ w_f^*\Lambda_f\Delta_f^*\right)\right]$$

so that

$$\hat{\rho}^{(1)} \ = \ \frac{-E\left[\left(\psi_f-\frac{\alpha}{\alpha+\xi}E[\psi_f]\right)\left(\frac{\alpha w_f^*}{\alpha+\xi-1}(r_*-\widetilde{\rho}_f) \ - \ w_f^*\Lambda_f\Delta_f^*\right)\right]}{1+E\left[\left(\psi_f-\frac{\alpha}{\alpha+\xi}E[\psi_f]\right)\left(\frac{\alpha+\xi}{\alpha+\xi-1}\left(2(\hat{\rho}^*-\rho_*)\lambda_*(f)\right)\right]}$$

Q.E.D.

C Equilibrium RRP choice: Proofs

By assumption, the objective of the fund is to maximize

$$\sum_b \frac{r_f(b)^{1-\alpha_b-\xi} - \widetilde{\rho}(\theta) r_f(b)^{-\alpha_b-\xi}}{r_f(b)^{-\alpha_b} w_f \; + \; F_{-f}(b)} \; + \; \widetilde{\rho}(\theta) d_f \; - \; (\xi_f(\theta_f \Delta_f) \; + \; 0.5\beta_f(\theta_f \Delta_f)^2)\,,$$

where

$$\widetilde{\rho}(\theta) \;=\; (\rho_* + (1-\theta)(\rho - \rho_*))\,.$$

Importantly, as above, funds are strategic in their trading decisions in the T-bill market and internalize their price impact: In equilibrium, investing $(1-\theta)\Delta_f$ of cash into T-bills moves the rate ρ by $\gamma_f(1-\theta)$, so that

$$\widetilde{\rho}(\theta) \;=\; (\rho_* + (1-\theta)(\rho - (1-\theta)\gamma_f - \rho_*))$$

As a result, the part of the objective that depends on θ can be rewritten as

$$(\rho_* + (1-\theta)(\rho - (1-\theta)\gamma_f - \rho_*))\Delta_f - (\xi_f(\theta_f \Delta_f) \; + \; 0.5\beta_f(\theta_f \Delta_f)^2)\,.$$

Optimizing over θ implies a demand function of (see, e.g., Malamud and Rostek (2017))

$$1 - \theta_f(\hat{\rho}) \;=\; \frac{\hat{\rho} - \rho_* + \xi_f}{\gamma_f + \beta_f \Delta_f}\,,$$

and hence (6) takes the form

$$D_f^T(\rho) \;=\; \frac{\hat{\rho} - \rho_* + \xi_f}{\gamma_f + \beta_f \Delta_f} \Delta_f\,,$$

so that we recover the upward-sloping demand curves (6), but the coefficients $a_*(f)$, $\lambda_*(f)$ are endogenous, determined in equilibrium through the strategic interaction of funds in the T-bill market. We will need the following characterization of this strategic interaction and equilibrium price impacts γ_f from Malamud and Rostek (2017).

Proposition C.1 *We have*

$$\gamma_f \;=\; \frac{2\beta_f\Delta_f}{\beta_f\Delta_f(\lambda+b)-2+\sqrt{(\beta_f\Delta_f(\lambda+b))^2+4}}\,,$$

where $b>0$ is the unique solution to

$$\sum_f \left(2+\beta_f(\lambda+b)+\sqrt{(\beta_f\Delta_f(\lambda+b))^2+4}\right)^{-1} \;=\; 0.5\frac{b}{\lambda+b}\,.$$

When $F\to\infty$ and $\beta_f=O(1)$, this gives $b=b_0+b_1F+O(F^{-1})$ with

$$b_1 \;=\; \sum_f(\beta_f\Delta_f)^{-1}/F$$

and

$$b_0 \;=\; -\sum_f(\beta_f\Delta_f)^{-2}/(Fb_1)\,.$$

Proof of Proposition C.1. Equilibrium price impacts satisfy

$$\gamma_f \;=\; \frac{1}{\lambda+b-(\gamma_f+\beta_f)^{-1}}$$

where

$$b \;=\; \sum_f(\gamma_f+b_f)^{-1}\,,$$

and the first claims follow by a direct calculation. To prove asymptotics, we note that, with $b=b_0+Fb_1+O(F^{-1})$, we get

$$\begin{aligned}
&2+\beta_f(\lambda+b)+\sqrt{(\beta_f(\lambda+b))^2+4}\\
&\approx\; 2+\beta_f(\lambda+b_0+b_1F)+\beta_f b_1F(1+(\lambda+b_0)/(b_1F))\\
&=\; 2\beta_f b_1F\Big(1+\frac{1+\beta_f(\lambda+b_0)}{b_1\beta_fF}\Big)
\end{aligned}$$

so that

$$\begin{aligned}
&\sum_f (2\beta_f b_1 F)^{-1}(1 - \frac{1+\beta_f(\lambda+b_0)}{\beta_f b_1 F}) \\
&= \ 0.5\frac{b_0+b_1F}{\lambda+b_0+b_1F} \ = \ 0.5(b_1F)^{-1}(b_0+b_1F)(1-\frac{(\lambda+b_0)}{b_1F}) \\
&= \ 0.5(1-\lambda/(b_1F))
\end{aligned}$$

Equating the coefficients gives

$$b_1 \ = \ E[\beta_f^{-1}/w_f^*]$$

and

$$b_0 \ = \ -\sum_f \beta_f^{-2}/(Fb_1)$$

Q.E.D.