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

Sebastian Doerr† Egemen Eren‡ Semyon Malamud§

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Abstract

We present a new channel through which US money market funds (MMFs) affect the pricing of near-money assets and the convenience yield on T-bills. We build a theoretical model in which MMFs' strategic interactions generate frictions that are exacerbated by illiquidity in the T-bill market. Using instrumental variables, we show that MMFs have an economically significant price impact in the T-bill market. Consistent with strategic behavior, they internalize this price impact when setting repo rates. Moreover, they tilt their portfolios towards repos with the Federal Reserve when the T-bill market is illiquid. We provide evidence suggesting that the frictions highlighted in our analysis drive a sizeable part of common measures of T-bill convenience yields, especially since 2022. Our results have implications for monetary policy transmission, government debt issuance, and regulation of the MMF industry.

Keywords: T-bills, repo, money market funds, near-money assets, liquidity, convenience yield
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†Bank for International Settlements Email: sebastian.doerr@bis.org
‡*Corresponding author.* Bank for International Settlements Email: egemen.eren@bis.org
§Swiss Finance Institute, EPF Lausanne, and CEPR; Email: semyon.malamud@epfl.ch

1 Introduction

US Treasury bills (T-bills) and repurchase agreements (repos) are among the most important instruments of global finance. T-bills are considered as highly liquid and viewed as the global risk-free asset, commanding a sizable convenience yield in the form of a safety and liquidity premium (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), and the reverse repo (RRP) facility of the Federal Reserve constitutes a critical monetary policy instrument (Afonso et al., 2022a).[1]

US money market funds (MMFs) play a key role as investors in these near-money assets. MMFs are short-term investment vehicles with total assets under management (AUM) of about $6 trillion as of mid-2023, equal to about 20% of US GDP or total commercial bank assets. MMFs' investments in T-bills and repos amount to more than $3 trillion. On aggregate, MMFs' average market share in the T-bill market is 20%, and their holdings significantly co-move with the T-bill supply, suggesting an important role for MMFs as marginal investors.

We present a new channel through which MMFs affect the pricing of T-bills and repos. Our analysis is motivated by the significant role of MMFs in the T-bill market and the high concentration in the MMF sector, as well as recent market stress episodes highlighting the importance of liquidity conditions in the Treasury market for financial markets (e.g. Duffie, 2020). We build a theoretical model in which MMFs' strategic interactions generate frictions that are exacerbated by illiquidity in the T-bill markets. Using instrumental variables, we demonstrate that MMFs have a price impact in the T-bill market that intensifies with market illiquidity. This finding suggests that T-bill markets may not be as liquid as usually assumed in the literature, and that this illiquidity has implications for key variables for the macroeconomy, such as the T-bill rates or the convenience yields on T-bills. Second, using a granular holding-level dataset, we show that MMFs internalize their price impact when they set repo rates and that they tilt their portfolios towards the RRP facility when the T-bill market is illiquid. Finally, we provide evidence suggesting that the frictions

[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.

uncovered in our analysis have driven a sizeable part of common measures of the T-bill liquidity premium, especially since 2022.

The key insight from the model is that large and strategic players active in multiple markets internalize their price impact in each market and adjust their portfolio allocations accordingly. We model MMFs as strategic players in the repo market with banks and 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. The key model friction is the price impact of MMFs in the T-bill market, which increases with market illiquidity. Reflecting market concentration, MMFs also have pricing power in the repo market, subject to a downward sloping demand curve by banks. MMFs strategically set repo rates, taking into account their price impact in the T-bill market. In equilibrium, the amount of "residual cash", i.e., what MMFs have left over from lending to banks and need to invest in T-bills, is the key variable to understand MMFs' impact on T-bill rates. In particular, a greater residual cash share is predicted to have a negative effect on T-bill rates (and hence a positive effect on the RRP-Tbill spread). The model also allows MMFs to invest in the RRP facility, which has an interest rate administered by the Federal Reserve, making the RRP-Tbill spread the main outcome variable in our analysis. The existence of the RRP facility alleviates but does not fully eliminate the impact of MMFs' portfolio allocation on T-bill rates.

We provide robust causal evidence that MMFs indeed have a price impact in the T-bill market and that it intensifies with market illiquidity. To establish causality, we devise two instrumental variables guided by our model. Our first instrument exploits exogenous changes in the demand for repos by European banks due to 'window dressing' for regulatory proposes. The Basel III leverage ratio allows European banks to report their leverage based on a quarter-end snapshot of their balance sheet, as opposed to a measure based on the daily average of the balance sheet over the entire quarter. This leads to quarter-end window dressing for European banks, which sharply contract their repo transactions (e.g. Aldasoro, Ehlers and Eren, 2022). Importantly, the quarter-end retrenchment by European banks is driven by regulation, and not by the prevailing conditions in the repo or T-bill market, nor by MMFs' behavior. Lower demand for repos means that MMFs have more residual cash they can invest in T-bills. Consistent with our model prediction, our estimates show that a one standard deviation increase in the residual cash share (or 22%) leads to an almost 7 basis point increase in the 1-month RRP-Tbill spread. We provide robustness checks using a second instrument that also follows directly from our theory. In the model, higher market concentration in the repo market leads to higher repo rates, which lowers banks' aggregate demand for repos. We hence use the Herfindahl-Hirschman Index (HHI) of market concentration in the bank repo market as an instrument for the "residual cash share".

To analyze the underlying channels in the model, we use a detailed dataset of US MMFs' individual portfolio holdings. The data, obtained from MMFs' regulatory filings, cover the universe of US MMF funds and provide detailed information on contract characteristics for each holding as monthly snapshots between February 2011 and June 2023. The holding-level dataset allows us to include a battery of fixed effects to rule out potential confounding factors.

Consistent with the model's predictions, we find that MMFs internalize their price impact in the T-bill market when setting repo rates. Moreover, they take into account liquidity conditions in the T-bill market when deciding on their portfolio allocations. First, we show that measures of funds' bargaining power in the repo market correlate positively with repo rates between MMFs and banks. In contrast, funds' market share in the T-bill market negatively correlates with repo rates. The latter effect is stronger when liquidity in the T-bill market is low, and funds' price impact is stronger. Second, funds with a higher residual cash share allocate relatively more to the RRP facility, in particular when the T-bill market is less liquid. These results remain robust when including time-varying fixed effects to rule out alternative explanations arising from potential differences in the time-varying unobservable bank, instrument, or fund-type characteristics, as well as macroeconomic factors.

These findings offer a new interpretation of the liquidity premium/convenience yields on T-bills. Common measures of liquidity premia compare the rates on T-bills with those of equally safe and less liquid assets. Importantly, they assume negligible intermediation frictions and a highly liquid T-bill market. As a result, a higher liquidity premium is usually interpreted as an increased investor preference for liquidity. However, through the lens of our model, a higher measured liquidity premium could also reflect a greater price impact of MMFs, a force that is expected to be larger when T-bill markets are less liquid. In fact, our model suggests that the common measures of the liquidity premium of T-bills increase when the T-bill market is more illiquid.

Using instrumental variables, we show that MMFs' residual cash indeed has an economically and statistically significant effect on the liquidity premium, measured as the 1-month General Collateral (GC) repo and T-bill spread.[2] In terms of magnitudes, the partial impact of a one standard deviation increase in *residual cash share* (or 22%) on the GC repo-Tbill spread is sizeable and equivalent to the effect of a 1 percentage point rise in the federal funds rate or a fifth of a percent decrease in the bills-to-GDP ratio. We further show that this effect operates through the RRP-Tbill spread, not through the GC repo-RRP spread, which is in line with the effect operating through the T-bill market. We also provide evidence suggesting that the frictions highlighted by our model have driven a sizable part of the variation in the measured liquidity premium of T-bills, especially since 2022.

Our results have implications for the transmission of monetary policy, government debt issuance, and the regulation of MMFs. First, MMFs typically receive inflows when the federal funds rate increases (e.g. Duffie and Krishnamurthy, 2016; Drechsler, Savov and Schnabl, 2017; Xiao, 2020). Our results suggest that these inflows, by increasing MMFs' demand for T-bills, put downward pressure on T-bill rates due to MMFs' price impact, weakening the transmission mechanism of monetary policy. A larger central bank balance sheet with greater availability of the RRP facility can partly offset this channel. Moreover, our results highlight that liquidity conditions in the T-bill market are an important factor in monetary policy transmission. Second, as the price impact of MMFs arises from supply-demand imbalances in the T-bill market, targeted government debt issuance could alleviate these imbalances, improving liquidity and increasing government revenues. Third, reforms that alter concentration in the MMF industry, such as those implemented in October 2016, can affect the pricing of near-money assets by altering the trade-offs funds face in their portfolio allocation.

[2] The 1-month General Collateral (GC) repo is collateralized by US Treasuries. As a result, it is considered as safe as T-bills, but less liquid since it cannot be liquidated before it matures.

Related literature. A large literature investigates liquidity premia on near-money assets, in particular T-bills. Krishnamurthy and Vissing-Jorgensen (2012) document that Treasuries have a convenience yield due to their safety and liquidity.[3] Consequently, they find that the supply of T-bills affects this convenience yield. Greenwood, Hanson and Stein (2015) also show that investors derive monetary benefits from holding short-term securities issued both by the government and private intermediaries.[4] Nagel (2016) instead argues that the liquidity premium is explained by the opportunity cost of money, as T-bills are close substitutes to money. As a result, the liquidity premium co-moves with the level of the federal funds rate, which drives the opportunity cost of money.[5] Focusing on the post-GFC period, d'Avernas and Vandeweyer (2023) show that the scarcity of T-bills available to shadow banks affects the liquidity premium, as banks' large reserve balances and capital regulation lead to market segmentation. Further, Acharya and Laarits (2023) argue that the convenience yield of Treasuries reflects their role as a hedge against shocks.

Our analysis offers novel insights on the determinants of the liquidity premium/convenience yield on T-bills. We provide evidence that intermediation frictions in the money market fund sector and their interaction with liquidity conditions in the T-bill market affect the pricing of near-money assets. Our results suggest that part of what is commonly attributed to the liquidity premium reflects MMFs' strategic decision of how to allocate their AUM to repos, the RRP, and T-bills. A decomposition exercise suggests that since 2022, intermediation frictions and T-bill market illiquidity have been important drivers of the liquidity premium. Our results also have more general implications for the interpretation of convenience yields measured as spreads in markets in which agents are not price takers.

Our paper also provides new insights into the important role of MMFs in short-term money markets[6] as well as in the transmission of monetary policy through banks and non-bank lenders

[3]An earlier literature also finds a convenience yield in government debt similar to money (e.g. Amihud and Mendelson, 1991; Duffee, 1996; Longstaff, 2004).

[4]Similarly, Krishnamurthy and Vissing-Jorgensen (2015) and Sunderam (2015) highlight the special role of short-term debt in the economy and discuss the implications of its supply by the government and the private sector. Lenel, Piazzesi and Schneider (2019) tie the convenience yield on short-term bonds to demand by intermediaries to back inside money.

[5]This result suggests a high elasticity of substitution between T-bills and other forms of money. Krishnamurthy and Li (2022) argue, however, that in presence of non-linearities, they are imperfect substitutes.

[6]See Kacperczyk and Schnabl (2013); Chernenko and Sunderam (2014); Krishnamurthy, Nagel and Orlov (2014);

(e.g. Duffie and Krishnamurthy, 2016; Drechsler, Savov and Schnabl, 2017; Xiao, 2020). By jointly accounting for MMFs' optimal price setting and asset allocations between T-bills, the RRP, and repos, we provide a novel channel through which frictions specific to MMFs can weaken the transmission of conventional monetary policy, and how unconventional monetary policy, in the form of the RRP facility, can partially offset this effect.[7] In contemporaneous work, Stein and Wallen (2023) also study the impact of intermediation frictions on the spread between the RRP and T-bills, but in a setup with heterogeneous preferences among a set of perfectly competitive MMFs. Our results also highlight the importance of liquidity conditions in the Treasury market for the effectiveness of monetary policy, thereby complementing work mostly focused on the Covid-19 period (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).

Finally, our findings speak to the broader literature on intermediary asset pricing (e.g. He and Krishnamurthy, 2013; Brunnermeier and Sannikov, 2014; Adrian, Etula and Muir, 2014; He, Kelly and Manela, 2017; Gromb and Vayanos, 2018; Siriwardane, Sunderam and Wallen, 2022; Du, Hébert and Huber, 2023, among others). The key insight from our theoretical and empirical analysis of heterogeneous intermediaries is that when large and strategic intermediaries are active in multiple markets, they internalize their price impact in each market and choose prices and portfolio allocations accordingly. While we study this problem within the context of MMFs and their impact in repo and T-bill markets, this framework might apply more generally in other settings that feature large and strategic intermediaries active in multiple asset classes.

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).

[7] See also Martin, McAndrews, Palida and Skeie (2019) and Infante (2020) for a discussion of the RRP and its impact on short-term markets.

2 Institutional details and stylized facts

US MMFs are short-term investment vehicles with total assets under management of around $6 trillion as of June 2023, averaging about 20% of US GDP or total US commercial bank assets.[8] The weighted average maturity of the holdings of the median fund is around one month, making their behavior key to developments at the short end of the yield curve.

MMFs' investments in near-money assets, i.e., T-bills, the RRP, and repos with banks, amount to more than $3 trillion (see Figure 1). Throughout the sample, on aggregate, MMFs' average market share in the T-bill market is 20%, with a high of 45% during the Covid-19 crisis. Moreover, their holdings significantly co-move with the T-bill supply, suggesting an important role for MMFs as marginal investors in this market.[9] MMFs are the single largest investor group in the RRP facility, representing 89% of its usage since its inception in September 2013 (Afonso, Cipriani and La Spada, 2022b). Finally, they provide substantial repo funding to banks, averaging more than $600 billion per month throughout our sample and reaching a maximum of around $1 trillion at the beginning of 2020.

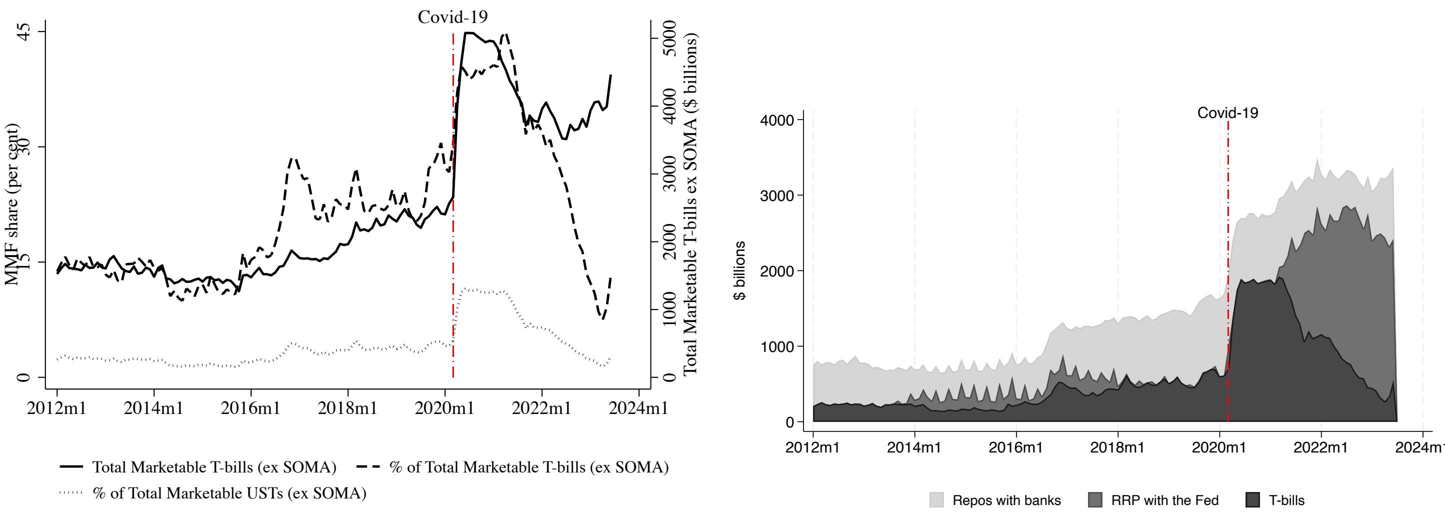
MMFs are large players in short-term markets and there is significant market concentration across funds both in the repo market and the T-bill market. Market shares of individual funds in the repo market and the T-bill market are positively correlated, with a correlation coefficient of 0.55 (Figure 2(a)). This observation serves as one building block of our theoretical framework, in which we model MMFs as strategic agents trading off their pricing power in the repo market versus their price impact in the T-bill market.[10]

[8]We focus on three major types of funds. *Treasury funds* are only allowed to invest in T-bills and repos backed by Treasury securities. *Government funds* are in addition also allowed to invest in agency debt and repos backed by agency collateral. *Prime funds* can in addition invest in unsecured instruments, such as commercial paper and certificates of deposits, which are typically riskier. Since we are interested in near-money assets, we focus on MMF investments into T-bills and repos with banks and the Federal Reserve.

[9]A regression of changes in MMF T-bill holdings on changes in the T-bill supply (excluding holdings at the Fed's SOMA portfolio) yields a statistically significant (at 1%) coefficient of 0.45, suggesting that for every one unit of new T-bill issued, MMFs on average absorb 0.45.

[10]The evidence provided in this paper and in Hu, Pan and Wang (2021) and Aldasoro, Ehlers and Eren (2022) is consistent with MMFs having pricing power in the overall repo market with banks. In contrast, Huber (2022) finds that dealers have pricing power whereas MMFs value the stability of lending relationships in overnight repos collateralized by US Treasuries. MMFs valuing the stability of repo lending relationships or accepting markdowns from dealers as a way to avoid price impact in the T-bill market could be an alternative micro foundation for the model, but ultimately the trade-offs MMFs face would remain similar.

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



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

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

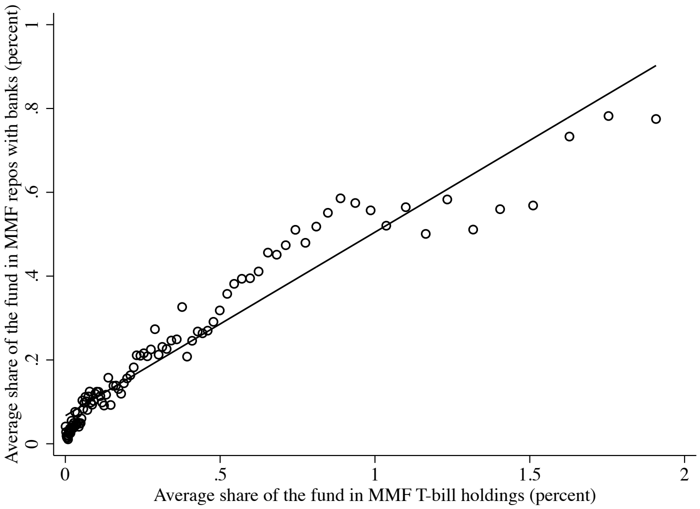
Notes: In Panel 1(a), the solid line is the time series of total marketable T-bills excluding those held at the SOMA portfolio. The dashed line shows the MMF share of holdings of the total. The dotted line shows the MMF share of total holdings of all US Treasuries, excluding those held in the SOMA portfolio. In Panel 1(b), the darkest area shows the total T-bill holdings of MMFs, the medium dark area shows total MMF investments in the RRP facility, and the light-gray area shows total MMF repos with banks. Source: Crane Data, US Treasury.

Finally, Figure 2(b) shows that funds' portfolio allocation between T-bills and the RRP is correlated with market liquidity in the T-bill market. When the market is less liquid (measured by Amihud illiquidity, where higher values indicate lower liquidity), funds' portfolios are tilted towards the RRP, relative to T-bills. The correlation shown in Figure 2(b) suggests that for one standard deviation (sd) higher Amihud illiquidity, the share of funds allocated to the RRP is 5.7 pp higher (17% of the sd).[11]

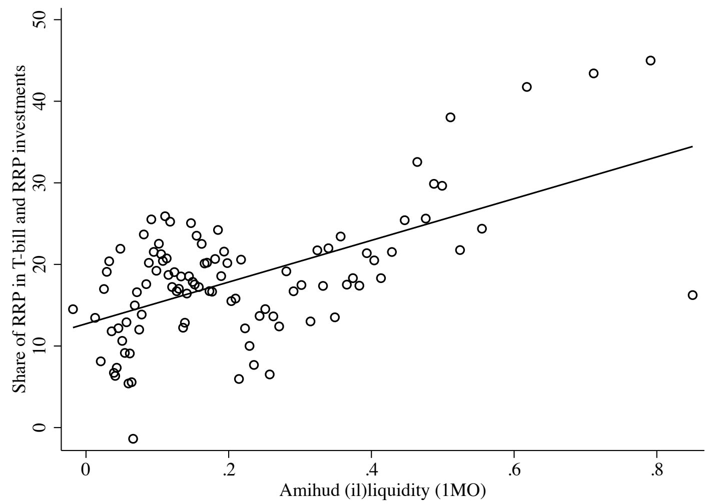
Building on these stylized facts, in the following section we delve deeper into understanding the trade-offs funds face, the role of market liquidity, and how these factors determine MMFs' portfolio allocations and thereby the pricing of near-money assets.

[11] We study the allocation of funds between T-bills and the RRP facility in detail in Section 5.

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



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

Note: In Panel 2(a) we plot the market share of each individual fund in the repo market on the y-axis against its market share in the T-bill market on the x-axis, both averaged across all months. In Panel 2(b) we plot the share of investments in the RRP out of total T-bill and RRP investments on the y-axis against the Amihud illiquidity index, multiplied by one million, on the x-axis. For the Amihud illiquidity, higher values correspond to lower liquidity in the T-bill market using weekly volumes. Results are conditional on fund-fixed effects. For expositional clarity, we remove outliers. Source: Crane Data, Federal Reserve Bank of New York.

3 A model of MMF intermediation of 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 different MMFs. MMFs interact with banks in the repo market and have pricing power. Any residual assets under management that MMFs do not lend to banks in equilibrium, they split between T-bills and the RRP. As large players, MMFs have a price impact in the T-bill market. Strategic funds trade off pricing power in the repo market and price impact in the T-bill market. Allocations between different instruments are affected by the liquidity conditions in the T-bill market.

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

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

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. 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.[13] The objective of fund f is thus to maximize the

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

[13]Most of the tri-party repo transactions take place earlier in the morning whereas RRP facility and T-bill auctions take place later in the day.

excess returns (markups) from lending to bank b over $r_f(b)$:

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

Funds behave strategically because, through the success probability term $\pi_f(r_f(b);b)$, they are in direct competition with other funds. The following is true.

Proposition 3.1 (Equilibrium in the repo market) *Suppose that* $w_f = w_f^*/F$, *where* w_f^* *is 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* w_f *(capturing the fund's market power in the repo market) as well as on* $H(W)$. *Furthermore, the volume of borrowing by bank* b *from fund* f, $\ell(r_f(b))\pi_f(r_f(b);b)$, *is monotone increasing in* w_f.

Proposition 3.1 shows how lower competition in the repo market makes it optimal for funds to charge higher markups. The size of these markups increases in the concentration in the repo market, captured by the Herfindahl Index $H(W)$.

The following corollary will serve as part of our identification strategy in the empirical analysis motivating the use of instrumental variables.

Corollary 3.2 *Define residual cash as the amount of assets under management not invested into repos with banks. Then, negative shocks to bank repo demand increase the residual cash. Similarly, positive shocks to repo market concentration (as captured by* $H(W)$*) increase residual cash. Both*

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

of these shocks only affect the equilibrium spread between the RRP rate and the T-bill rate through the residual cash.

3.2 T-bill market

We now introduce a simple model for rate determination in the T-bill market. The supply 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

$$D(\rho) = a + \lambda\rho\,, \tag{2}$$

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 MMFs hold non-trivial amounts of T-bills even when ρ is significantly below ρ_*, suggesting that some frictions prevent MMFs from selecting this corner solution (see Sections 6 and A.1). A natural follow-up question then is whether MMFs respond *elastically* to changes in the T-bill rate. In the 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:

$$D_f^T(\rho) \;=\; (a_*(f) + \lambda_*(f)(\rho - \rho_*))\Delta_f \tag{3}$$

with 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. Under the above assumptions, the T-bill rate is pinned down by the market-clearing condition

$$a + \lambda\rho \; + \sum_f (a_*(f) + \lambda_*(f)(\rho - \rho_*))\Delta_f \; = \; S \, . \tag{4}$$

Solving equation (4), we arrive at the equation

$$\rho \; = \; \rho_* \; + \; \underbrace{\frac{S - a - \sum_f a_*(f)\Delta_f}{\lambda + \sum_f \lambda_*(f)\Delta_f}}_{supply-demand\ imbalance}, \tag{5}$$

showing explicitly how MMFs' demand affects the equilibrium T-bill rate. The goal of this section is to micro-found the demand functions (3) through the strategic behavior of MMFs in the Tbill market. As we show below, such strategic behavior generates novel testable predictions about the way MMFs internalize their price impact in the T-bills market when they set rates in the repo market.[15]

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

$$\Delta_f \; = \; d_f - \underbrace{\sum_b (R_*/r_f(b))^{\xi} \frac{r_f(b)^{-\alpha_b} w_f}{\Gamma_*(b)}}_{repo\ lending\ given\ banks'\ demand\ curves} \, . \tag{6}$$

Equation (6) describes the key mechanism of our model: If a fund sets higher rates $r_f(b)$ for repos with banks, banks' demand for repos falls, leaving the fund with more residual cash. The fund then has to invest this cash into T-bills. If the T-bill market is illiquid, buying a lot of T-bills has a

[15] One could also consider two layers of strategic market impact internalization. In equilibrium, the illiquidity of the T-bill market and the price impact of a given fund f affect (i) the fund's rate setting in the repo market and (ii) the repo rates set by other funds. In what follows, we ignore the latter channel because it has lower-order effects and focuses on channel (i).

stronger price impact, making this investment less attractive. When optimizing profits, funds take this price impact into account.

Proposition A.3 in the Appendix shows how a strategic change in the repo rate, through its impact on the residual cash and a fund's demand function for T-bills, affects the equilibrium T-bill rate ρ. Funds rationally anticipate their price impact and take it into account when setting the repo rate $r_f(b)$. With the pass-through coefficient derived in Proposition A.3, we can write down the first-order condition of each fund concerning the rate $r_f(b)$ it charges to a particular bank and compute the equilibrium link between the repo rates set by a fund and the T-bill rate.

Proposition 3.3 (Equilibrium Repo Markups) *The optimal repo rate set by fund f for bank b is monotone increasing in the fund's market power, as captured by w_f^*, and is negatively related to the fund's share of the residual cash invested into T-Bills. The latter effects are amplified when the T-Bill market is illiquid.*

The intuition behind Proposition 3.3 is as follows: Funds with more market power in the repo market charge higher rates. However, funds with more residual cash strategically internalize their price impact on T-bill rates. 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 more favorable 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.[16] In this case, absent market power, fund f charges the rate

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

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

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

$$\hat{\rho}^* = \rho_* + (\lambda + \bar{\lambda})^{-1}\Big(\underbrace{S}_{supply} - \underbrace{\Big(a + \sum_f a_*(f)\Delta_f\Big)}_{demand}\Big), \tag{7}$$

where we have defined

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

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 (7). The following is true.

Proposition 3.4 (Equilibrium T-bill rate) *The equilibrium spread between the RRP rate and the T-bill rate depends positively on the residual cash share. The effect is stronger when the T-bill market is less liquid.*

3.5 Equilibrium RRP choice

Our derivations in the previous sections are based on the assumption of downward-sloping demand curves (equation (3)) for T-bills with respect to price (upward-sloping with respect to yields). 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 the RRP is associated with an implicit, non-monetary cost. This cost might be driven by several factors about which we remain agnostic. One possible factor could be precautionary reasons. Each fund faces the same counterparty limits set by the Federal Reserve. Even though funds are typically all comfortably below this limit, a buffer could be preferred in case sudden inflows necessitate higher RRP take-up. Alternatively, there might be an inconvenience attached to constantly rolling over the RRP investment in comparison to buying and holding T-bills for a month. Finally, funds might have reputational concerns, whereby they might fear that their RRP investments might be interpreted by their investors as an inability to make successful active investment choices.

We assume that this cost is given by

$$\xi_f(\theta_f \Delta_f) \; + \; 0.5\beta_f(\theta_f \Delta_f)^2 \,, \tag{8}$$

where θ_f is the fraction of residual cash invested into RRP. In Appendix A.4, we use the formalism of Malamud and Rostek (2017) to develop a model of strategic trading for funds optimizing the trade-off between price impact and the cost (8). First, more 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 (2) 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 the RRP. Jointly, these observations imply that funds with more residual cash Δ_f invest more into the RRP, and more so when markets are illiquid. As a result, when T-bill markets are illiquid, fund demand becomes less elastic with respect to changes in the T-bill rate. The following result formalizes this intuition.

Proposition 3.5 *The following is true.*

- *A drop in T-bill liquidity leads to an increase in the share of residual cash invested in the RRP.*
- *Funds with more residual cash allocate a greater share to the RRP, and more so when markets are illiquid.*

The parameter ξ_f plays the role of a "convenience yield" of Treasuries for fund f. Naturally, this convenience yield is translated into a discount in equilibrium: When ξ is large, the T-bill rate

ρ will drop below the RRP rate ρ_*. A striking implication of our model is that ξ only affects ρ when T-bills are illiquid, as is shown by the following proposition.

Proposition 3.6 (Convenience Yield and Illiquidity) *The T-bill rate depends on ξ only through its interaction with illiquidity. In particular, the sensitivity $\frac{\partial}{\partial \xi}(\rho_* - \rho) > 0$ is monotone, increasing in illiquidity, and vanishes when T-bills are sufficiently liquid.*

Proposition 3.6 implies that, in our model setting, the measured gap, T-bills command an illiquidity premium: Their yields drop (prices increase) when they are less liquid. Thus, an empirically observed positive gap $\rho_* - \rho$ might reflect the interaction of two mechanisms reinforcing each other: (1) T-bills are more convenient than the RRP; (2) T-bills are illiquid. We discuss the empirical implications of Proposition 3.6 in Section 6.

4 The aggregate impact of MMFs on the pricing of T-bills

In this section, we test the following prediction on the aggregate impact of MMFs on T-bill rates:

Prediction 1. By Proposition 3.4, the equilibrium T-bill rate depends negatively on funds' residual cash share, in particular when liquidity in the T-bill market is low.

In order to tackle identification challenges arising from possible endogeneity of funds' residual cash share, we resort to our model to construct instrumental variables and establish causality. By Corollary 3.2, negative shocks to banks' repo demand increase the residual cash share. Similarly, positive shocks to repo market concentration (as captured by $H(W)$) increase the residual cash share (Proposition 3.1). Both shocks only affect the equilibrium spread between the RRP rate and the T-bill rate through the residual cash. Therefore, through the lens of the model, shocks to bank repo demand and to repo market concentration are relevant and satisfy the exclusion restriction.

4.1 Data description and summary statistics

We collect data on monthly averages of the 1-month T-bill rate, the rate on the RRP facility, the 1-month GC repo rate, the effective federal funds 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 a monthly series for the bills-to-GDP ratio, where we subtract the holdings of the Federal Reserve through its SOMA portfolio from bills. We use the weekly trading volume of T-bills from the Federal Reserve Bank of New York to construct an Amihud (2002) illiquidity measure using the spread between the 1-month T-bill rate and 1-month realized RRP rate and standardize it to a mean of zero and standard deviation of one in the regressions. For this measure, higher values correspond to lower liquidity. We also collect monthly data on holdings of short-term U.S. securities, in particular securities held by foreign banks, from the Treasury International Capital (TIC) System home page. We compute the following spreads: the RRP-Tbill spread as the realized rate on the overnight RRP facility compounded over a month and the 1-month T-bill rate in month t;[17] and the GC-Tbill spread as the spread between the 1-month GC repo rate and the 1-month T-bill rate, a common measure of the liquidity premium.

Our key independent variable, $residual\ cash\ share_t$, 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 than the amount of residual cash, follows from our model, but we show the robustness of our results to alternative definitions in the appendix.[18]

[17]We lag the compounded return on RRP by one month to make the returns comparable with the T-bill rate. In robustness checks, we also measure the 1-month expected RRP rate by adding the 1-month OIS rate and subtracting the current federal funds rate. The two measures are quantitatively similar.

[18]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 and endogenous quantity that depends 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 A.6). Instead, there is a direct link between the residual cash left over from repo lending and outcome variables.

We construct two instrumental variables for the residual cash share, which we discuss in further detail below. The first instrument $\%\Delta$ *Euro repo* is constructed as the change in the volume of repo transactions between US MMF and European banks. This instrument exploits changes in the demand for repos by European banks induced by window dressing for regulatory purposes at quarter-ends. Our second instrument, *HHI bank repo*, measures market concentration in the market for repos with banks. We construct the HHI of funds in the repo market by summing up the squared market share of each fund in the repo market.[19] It lies between 0 and 10,000.

Table 1 presents the summary statistics of our main variables over the 143 months in our sample period (2011m2 to 2022m12).[20]

4.2 MMFs' residual cash share and the RRP-T-bill spread

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

$$RRP\ (1M) - Tbill\ (1M)_t = \beta\ residual\ cash\ share_t + controls_t + \epsilon_t. \tag{9}$$

The dependent variable is the spread between the realized rate on the overnight RRP facility compounded over a month and the 1-month T-bill rate in month t.[21] We lag the 1-month realized RRP rate by one month to cover the same time period as the 1-month T-bill rate.[22] 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 (excluding SOMA portfolio holdings), as well as the VIX (Nagel, 2016; d'Avernas and Vandeweyer, 2023). We report

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

[20] Since the implementation of Basel III regulations, there have been calls for European banks to switch from quarter-end reporting which generates incentives for window dressing at quarter-ends as opposed to quarterly averaging. Starting in 2023, the repo volumes are smoother and we do not observe any quarter-end window dressing. Therefore, we end our sample period at the end of 2022.

[21] 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 set the RRP rate to zero prior to the introduction of the RRP.

[22] Alternatively, we also construct the expected 1-month RRP rate instead of the realized one by adding the 1-month OIS rate to the overnight RRP rate and subtracting the current federal funds rate. The results remain similar.

Table 1: **Summary statistics**

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
RRP(1M) - Tbill(1M)	143	-2	10.7	-44.71	44.25	-1
GC (1M) - 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
%Δ Euro repo (quarter-end)	48	-31.45	16.45	-75.94	.23	-29.6
HHI bank repo	143	260.37	72.9	160.12	384.69	278.59
FFR	143	.68	.88	.05	4.1	.14
log(bills to GDP)	143	-2.23	.28	-2.67	-1.43	-2.31
VIX	143	18.38	6.81	10.13	57.74	16.7

Note: This table reports summary statistics for the main variables used in the regressions. $RRP(1M) - Tbill\ (1M)$ 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 rates and realized overnight RRP rates compounded over a month to calculate the $RRP(1M) - Tbill(1M)$ spread. Prior to the introduction of the RRP facility, we use the 1-month T-bill rate. The $GC - Tbill$ 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. %Δ *Euro repo (quarter-end)* is the change in European banks' repo activity with US MMFs at quarter-ends. HHI *bank repo* measures the HHI of funds in the repo market and ranges from 0 to 10,000 (constructed by summing the squared market share of each fund in the repo market). *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 over GDP. To construct monthly GDP data, we interpolate quarterly data into monthly data. The VIX is the monthly average level of the index. P50 refers to the median. The sample is the monthly time series between February 2011 and December 2022. Source: Crane Data, FRED, Bloomberg, US Treasury.

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 positive effect on the RRP-Tbill spread. The reason is that funds' price impact exerts negative pressure on the T-bill rate, so $\beta > 0$. This follows directly from Equation (7). In addition, the model predicts that the effect of the residual cash share on the RRP-Tbill spread is stronger when the Treasury market is illiquid. To test this, we estimate the following regression similar to Equation (9):

$$RRP\ (1M) - Tbill\ (1M)_t = \beta_1\ residual\ cash\ share_t + \beta_2\ \ Amihud_t + \beta_3\ residual\ cash\ share_t \times Amihud_t + controls_t + \epsilon_t. \tag{10}$$

The variable *Amihud* denotes the Amihud liquidity measure. As higher values imply lower liquidity in the T-bill market, we expect $\beta_3 > 0$.

This analysis is subject to endogeneity concerns as the $residual\ cash\ share_t$ is an equilibrium outcome and we regress rates on quantities. Since changes in the T-bill rate could affect the residual cash share, coefficients in Equations (9) and (10) cannot be interpreted as causal.

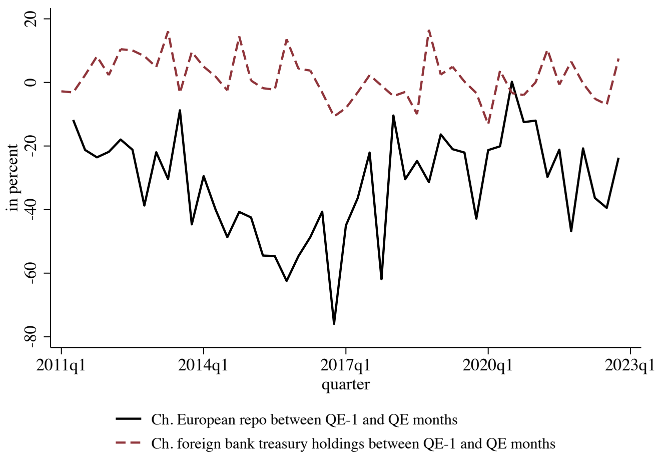
To establish a causal effect of the residual cash share on the RRP-Tbill spread, we devise an instrumental variable that exploits exogenous changes in the demand for repos by European banks at quarter-ends. The Basel III leverage ratio allows European banks to report their leverage based on a quarter-end snapshot of their balance sheet, as opposed to a measure based on the daily average of the balance sheet over the entire quarter. This leads to a pronounced quarter-end window dressing effect for European banks, which sharply contract their repo transactions around that time (black line in Figure 3, panel (a), as well as Aldasoro, Ehlers and Eren (2022)).[23] Due to lower demand for repos, MMFs subsequently have more residual cash to invest in T-bills. As shown in panel (b) of Figure 3, European banks' quarter-end change in repo transactions with MMFs has a strong negative correlation with funds' residual cash share. It is also important to note that the volume by which European banks retrench from repo markets is a decision taken at the bank headquarters for purposes of quarter-end reporting on compliance with Basel III regulations, and it is exogenous to MMFs.[24]

The exclusion restriction requires European banks' quarter-end retrenchment to be driven by their response to regulatory requirements. A violation of the exclusion restriction would be present if European banks increase their demand for T-bills at the same time as they reduce their demand for repos with US MMFs. If European banks would shift into T-bills at quarter-ends, then any observed decline in the T-bill rate would not only occur because of a change in MMFs' residual cash share but also because of higher demand by European banks. While no breakdown of T-bill

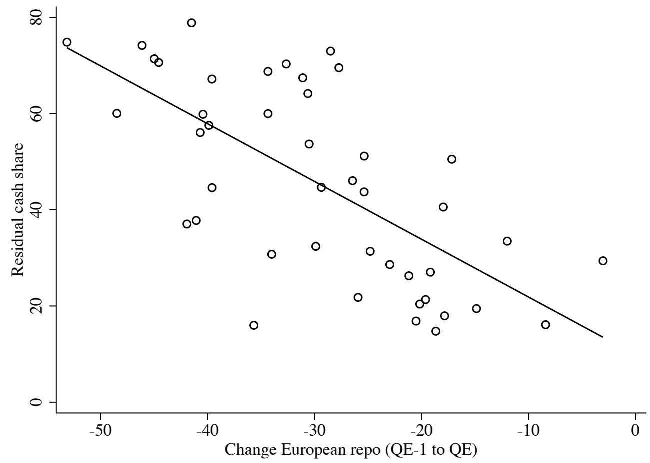
[23] Appendix Figure A2 provides European banks' repo activity at the monthly level, showing the contraction at quarter-ends. Note that this pattern has ended in 2023, with quarter-end repo borrowing being greater than the month before, possibly reflecting the recent harmonization efforts of Basel III regulations. Therefore, we end our sample at the end of 2022.

[24] Due to their short-term nature, repos are easier to adjust at quarter-ends than other activities. These banks typically return to repo markets shortly after the quarter end (Munyan, 2017).

Figure 3: Window dressing and the demand for repos by European banks



(a) European banks' demand for repos and foreign banks' demand for Treasuries



(b) European banks' demand for repos with MMFs and the residual cash share

Notes: Panel (a) plots the quarter-to-quarter change in European banks' repo activity with US MMF (black line) and the quarter-to-quarter change in foreign banks' holdings of short-term treasuries (red dashed line). Panel (b) plots the correlation between the quarter-to-quarter change in European banks' repo activity with US MMF against the *residual cash share*, which 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.

holdings by foreign banks *by country* is available, the US Department of the Treasury provides information on aggregate T-bills held by foreign banks in each month. As European banks are major global players, significant changes in their demand for T-bills are likely to affect the holdings of T-bills by foreign banks on aggregate. As shown in panel (a) of Figure 3, foreign banks' holdings of T-bills (red dashed line) change much less than European banks' demand for repos with US MMF at quarter-ends (black solid line). Moreover, Figure A1 in the Appendix shows that there is a precise zero relationship between quarter-end changes in European banks' demand for repos and quarter-end changes in foreign banks' holdings of T-bills. These patterns suggest that European banks' change in the demand for repos is uncorrelated with their demand for T-bills at quarter-ends, supporting the validity of our instrument. As we show below, our results are also robust to directly controlling for the change in foreign banks' holdings of T-bills at quarter-ends.

Table 2 shows that a higher residual cash share increases the RRP-Tbill spread. Column (1) reports results from a univariate regression and shows a positive correlation between *residual cash share* and the RRP-Tbill spread, significant at the 5% level. In column (2) we control for the variables that are commonly used in the literature to explain spreads, ie the federal funds rate, log(bills to GDP), and the VIX. The estimated coefficient on *residual cash share* increases in magnitude and becomes significant at the 1% level. The residual cash share explains a sizeable share of the variation in the RRP-Tbill spread. A Shapley decomposition of the total R^2 of 41% shows that over three-quarters are explained by the residual cash share, while the FFR, supply of Tbills and VIX jointly explain the remaining 25%.[25]

Column (3) investigates whether the effect of the residual cash share on the spread is stronger during times of illiquidity in the Tbill market. Consistent with the model's prediction, results for regression (10) show that the correlation is indeed significantly stronger when the Treasury market is illiquid.

To estimate the causal effect of the *residual cash share* on the RRP-Tbill spread, column (4) uses $\%\Delta$ *Euro repo* as IV. Since the IV only exploits quarter-end variation, the number of observations drops to 48 months. 2SLS results suggest a positive causal effect of the residual cash share on the RRP-Tbill spread, which is significant at the 1% level. The effective F statistic (as computed in Olea and Pflueger (2013)) equals 18.78, and when we compute the weak-instrument robust 95% confidence set for our estimates using the Anderson-Rubin procedure, the interval excludes zero. The 2SLS estimates are close in magnitude to their OLS counterpart in column (2).[26]

In terms of magnitudes, the partial impact of a one standard deviation increase in *residual cash share* (corresponding to a 22% increase) on the RRP-Tbill spread is 6.95 basis points (0.65 of the standard deviation). This effect is equivalent to the effect of a 0.5% decrease in the bills-to-GDP

[25]Note that in contrast to Nagel (2016), the FFR has no significant effect on the spread. This is to be expected, as in Nagel (2016) the positive effect of the FFR on the liquidity premium materializes because deposits pay lower interest than other near-money assets. Yet RRP investments are safe, highly liquid, *and* pay an interest rate that strongly co-moves with the FFR.

[26]When we restrict the sample to the 48 quarter-end months and estimate column (2), the coefficient estimate on free cash share is 0.371, compared to 0.368 for the full sample of 143 months.

ratio. Hence, MMFs' residual cash share has a statistically and economically significant impact on the RRP-Tbill spread.

Column (5) shows that the stronger effect of the residual cash share during periods of low liquidity is also present in 2SLS regressions. The residual cash share and its interaction with the illiquidity index are significant at the 1%

In sum, Table 2 provides strong support for key predictions of our model. A higher residual cash share increases the RRP-Tbill spread, and especially when the Treasury market is illiquid. In what follows, we will first discuss the additional tests and robustness checks we perform. In the next sections, we will provide micro-evidence on the channels underlying this result (Section 5); and then discuss the implications of our results for the measurement of the liquidity premium of T-bills (Section 6).

4.3 Additional tests

Controlling for foreign banks' demand for T-bills. As discussed above, if European banks' holdings for T-bills change systematically with their quarter-end changes in repo holdings, the exclusion violation would be violated. However, as we show in Table A1, columns (1) and (2), results in Table 2 are qualitatively and quantitatively similar when controlling for the change in foreign banks' holdings of T-bills at quarter-ends. The robustness of our results is consistent with the fact that there is a precise zero relationship between quarter-end changes in European banks' demand for repos and quarter-end changes in foreign banks' holdings of T-bills (see Figure A1).

Alternative instrumental variable We leverage our model to devise an additional instrumental variable. Following Proposition 3.1, we can instrument $residual\ cash\ share_t$ with the market concentration of MMFs in the repo market. 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. Appendix Figure A3, panel (a) shows a positive and significant correlation between $HHI\ bank\ repo$ and $residual\ cash\ share$.

Table 2: MMFs' residual cash share and the RRP-T-bill spread

VARIABLES	(1) OLS RRP-Tbill	(2) OLS RRP-Tbill	(3) OLS RRP-Tbill	(4) 2SLS RRP-Tbill	(5) 2SLS RRP-Tbill
residual cash share	0.23**	0.37***	0.33***	0.32***	0.32***
	(0.09)	(0.10)	(0.04)	(0.12)	(0.05)
Amihud			-14.52***		-22.42***
			(2.53)		(4.65)
residual cash share × Amihud			0.35***		0.47***
			(0.05)		(0.10)
FFR		-1.32	-4.45***	2.39	-3.10*
		(2.27)	(1.01)	(4.06)	(1.77)
log(bills to GDP)		-19.29***	-9.28***	-12.57***	-5.38***
		(4.55)	(1.94)	(3.80)	(1.48)
VIX		0.01	-0.38**	-0.12	-0.41***
		(0.31)	(0.17)	(0.35)	(0.16)
Observations	143	143	143	48	48
R-squared	0.22	0.41	0.71		
Anderson-Rubin test (p-val)				0.01	0.05
F stat				18.78	3.32
IV Confidence set 1				[0.14, 0.47]	[0.23; 0.38]
IV Confidence set 2					[0.23; 0.81]

Note: This table reports results for Equations (9) and (10). Variable descriptions and summary statistics can be found in Table 1. Data are at a monthly frequency between February 2011 and December 2022. The dependent variable is the RRP-Tbill spread. Columns (1) to (3) report the results of OLS regressions. Columns (4) and (5) report the second stage of 2SLS regressions, in which %Δ *Euro repo* instruments *residual cash share*. *Amihud* denotes the Amihud liquidity index, standardized to a mean of zero and standard deviation of one. Columns (4) and (5) restrict the sample to quarter-end months. Wherever applicable, we report the p-value of the Anderson-Rubin test and the effective F statistic as in Olea and Pflueger (2013). Columns (4) and (5) report weak-instrument robust 95% confidence sets for our estimates. 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.

A threat to the validity of this instrument is that the HHI reflects the variation induced by the MMF reform in 2016 (see Figure A3, panel b). The 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 a drastically higher concentration in the repo market (Aldasoro, Ehlers and Eren, 2022).

As resources moved from prime to government funds after the reform, not only the HHI but also the aggregate demand for repos could have changed, as government funds cannot invest in unsecured instruments. An increase in the demand for repos not matched by a concurrent increase in supply would be associated with higher repo rates but also more residual cash 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 IV regressions only for the post-reform period and control for the share of government funds over time.[27] Table A1, columns (3) to (5), in the Appendix reports results and confirms the positive effect of the residual cash share on the RRP-Tbill spread found in Table 2. Finally, column (6) reports the Hansen J-statistic when we include both instruments. Our results remain similar.

Alternative definitions of main dependent and independent variables. Table A2 replicates Table 2 but uses the log of total residual cash to GDP as the independent variable. Using this alternative measure of funds' footprint in the T-bill market yields qualitatively and quantitatively similar results. It also facilitates interpretation. For example, in column (3), a 2.5% increase in the ratio of residual cash to GDP has an effect on the RRP-T-bill spread that is similar to a 1% decrease in the ratio of T-bill supply to GDP. In addition, Table A3 uses the expected, rather than the realized, RRP-Tbill spread as the dependent variable.[28] Since the correlation between expected

[27] However, as shown in Figure A3, panel (a), the correlation between *HHI bank repo* and *residual cash share* is positive and significant both in the pre- and post-reform period.

[28] The expected 1-month RRP rate is calculated as the overnight RRP rate plus the 1-month OIS rate minus the effective fed funds rate.

and realized spread is very high, results are nearly identical to Table 2. Finally, Table A4 shows that our results are robust to alternative liquidity indicators, including the bid-ask spread.[29]

5 Micro evidence on the trade-offs and MMF portfolio allocation

In this section, we use contract-level data to test the following model predictions on the channels underlying our baseline results.

Prediction 2. By Propositions 3.1, the repo rate charged by a fund to a bank is positively related to the size of the fund in the repo market.

Prediction 3. By Proposition 3.3, funds with a higher market share in the T-bill market charge a lower repo rate as they internalize their price impact. This effect is stronger when the T-bill market is less liquid.

Prediction 4. By Proposition 3.5, funds with more residual cash allocate a greater share to the RRP, and more so when markets are illiquid.

5.1 Data description

We use a granular and rich dataset of US MMFs' portfolio holdings 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 June 2023. Holdings data are reported at each month's end.[30] 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 Treasury, Government Agency, or other collateral. US MMFs are only allowed to invest in dollar-denominated instruments. Therefore, all transactions are denominated in dollars.

[29] We also verified that our main results hold when we lag the right-hand side variables by one period (unreported).

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

To measure funds' market share ('FMS') in the market for repos with banks as well as the T-bill market, we define the following two metrics:

$$F\ MS\ bank\ repo_{f,t} = \frac{\sum_b bank\ repo_{f,b,t}}{\sum_f \sum_b bank\ repo_{f,b,t}} \times 100, \tag{11}$$

$$F\ MS\ treasury_{f,t} = \frac{amount\ treasury_{f,t}}{\sum_f amount\ treasury_{f,t}} \times 100, \tag{12}$$

where f denotes fund, b bank, and t the month. Higher values of $F\ MS\ bank\ repo$ ($F\ MS\ treasury$) proxy greater market power of a fund in the bank lending (T-bill) market. We compute analogous measures at the fund family level, denoted as $FF\ MS\ bank\ repo$ ($FF\ MS\ treasury$). In addition, we construct a measure of fund (fund family) bargaining power vis-a-vis a bank in the repo market. This measure captures the idea that if a bank relies heavily on a given fund (or fund family), then the fund (or family) can be expected to have a higher bargaining power. We construct two variables capturing this idea at the fund and the fund family level. These variables are denoted by $F\ bargaining\ power\ repo$ and $FF\ bargaining\ power\ repo$ and constructed in the following way:

$$F\ bargaining\ power\ repo_{f,b,t} = \frac{bank\ repo_{f,b,t}}{\sum_f bank\ repo_{f,b,t}} \times 100,$$

$$FF\ bargaining\ power\ repo_{ff,b,t} = \frac{bank\ repo_{ff,b,t}}{\sum_{ff} bank\ repo_{ff,b,t}} \times 100,$$

Table 3 provides summary statistics.

5.2 Repo pricing power versus T-bill price impact trade-off

To analyze the effects of funds' market shares in the repo market with banks and the T-bill market on repo rates charged to banks (Predictions 2 & 3), we estimate variants of the following regression:

$$rate_{i(f,b),t} = \beta_1\ F\ MS\ bank\ repo_{f,t} + \beta_2\ F\ MS\ treasury_{f,t} + controls_{i,t} + \theta + \varepsilon_{i,t}. \tag{13}$$

Table 3: Summary statistics

Panel (a): Summary statistics for variables in Table 4 (contract level data)

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
rate	278110	103.78	119.35	0	572	44
F MS bank repo	278110	1.84	2.12	0	11.89	.82
F MS treasury	278110	.8	1.14	0	15.72	.3
FF MS bank repo	278110	11.05	8.8	0	28.4	8.31
FF MS treasury	278110	7.55	5.49	0	26.53	7.04
F bargaining power (repo)	278110	3.99	7.17	0	100	1.58
FF bargaining power (repo)	278110	17.36	18.11	0	100	11.94

Panel (b): Summary statistics for variables in Table 5 (fund-time level data)

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
RRP share	13797	18.82	32.32	0	99.99	0
F residual cash share	13797	45.95	30.03	0	100	42.83
liquidity (Amihud index)	13797	0	1	-.7	6.39	-.32
1(debt ceiling)	13797	.22	.41	0	1	0

Note: This table reports summary statistics for the key variables used in the empirical analysis in Section 5. Using contract-level data, the upper panel reports the summary statistics of the variables used in Table 4. The sample period for the upper panel runs between February 2011 and June 2023, with holdings data reported at each month's end. *rate* refers to the repo rate and is in basis points. *F MS bank repo* (*FF MS bank repo*) is the market share of the fund (fund family) in the repo market (see Eq. 11). *F MS treasury* (*FF MS treasury*) is the market share of the fund (fund family) in the T-bill market (see Eq. 12). *F bargaining power* (*FF bargaining power*) measures a fund's (fund family's) bargaining power vis-a-vis a bank in the repo market. All variables are in percentage points. In the lower panel, we report the summary statistics of the variables used in Table 5 at the fund-time level. The sample period for the lower panel runs between October 2013 and December 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 to the RRP facility. *F residual cash share* is a fund's residual cash share. *liquidity* (*Amihud index*) is the Amihud liquidity index, where a higher value indicates lower liquidity. It is standardized to a mean of zero and a standard deviation of one. The dummy *debt ceiling* takes on a value of one during debt ceiling episodes. Source: Crane Data, Bloomberg.

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 $F\ MS\ bank\ repo_{f,t}$ and $F\ MS\ treasury_{f,t}$ denote fund f's market share in the bank repo and the T-bill markets in month t (as defined in Equations (11) and (12)). Each regression controls for the size and the maturity of the contract, while θ denotes different fixed effects we explain in more detail below. Standard errors are clustered at the fund level.

Our model predicts that both funds' market power and price impact in the T-bill market enter into consideration when setting repo rates. In particular, funds with higher market power (proxied by their market share) in the repo market are expected to charge higher rates (Prediction 2), while a higher market share in the T-bill market should lower repo rates charged by the same fund due to the internalization of its price impact (Prediction 3). We hence expect $\beta_1 > 0$ and $\beta_2 < 0$.

Regression equation (13) 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 repo 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. To address these challenges we include granular time-varying fixed effects. To account for time-varying factors that affect different collateral types (US Treasury, government agency, or other collateral), the regression includes time-varying fixed effects at the collateral type level. In addition, regressions include fund type*bank*time fixed effects. These fixed effects account for unobservable time-varying differences in bank characteristics, including changes in risk, size, or repo demand. And they allow these factors, including repo demand, to vary over time by fund type. Note that these fixed effects absorb any time-varying market power banks might have in this market which moves at the bank level over time. The regression coefficients hence capture the effects of MMFs' market power on repo rates when banks' market power is held constant.

Table 4 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. Column (1) reports a positive coefficient on $FMS\ bank\ repo$ ($\beta_1 > 0$) and a negative coefficient on $FMS\ treasury$ ($\beta_2 < 0$), both significant at the 1% level. Column (2) interacts $FMS\ treasury$ with the Amihud liquidity index to test the prediction that large funds internalize their price impact in the T-bill market, especially when liquidity in the T-bill market is low (Prediction 3).

Table 4: Funds have market power in the repo market, but also internalize their price impact in the T-bill market

VARIABLES	(1) rate	(2) rate	(3) FF rate	(4) rate	(5) FF rate	(6) rate	(7) FF rate
F MS bank repo	0.234***	0.236***					
	(0.073)	(0.073)					
FF MS bank repo			0.102**				
			(0.048)				
F bargaining power (repo)				0.038**		0.002	
				(0.017)		(0.013)	
FF bargaining power (repo)					0.066***		0.025**
					(0.019)		(0.010)
F MS treasury	-0.310***	-0.329***		-0.141**		-0.215***	
	(0.091)	(0.090)		(0.064)		(0.073)	
F MS treasury × Amihud		-0.135**		-0.130**		-0.149**	
		(0.066)		(0.064)		(0.065)	
FF MS treasury			-0.050		-0.016		-0.087**
			(0.055)		(0.035)		(0.038)
FF MS treasury × Amihud			-0.061***		-0.061***		-0.072***
			(0.014)		(0.015)		(0.014)
Observations	275,331	275,331	382,985	275,331	382,985	275,292	382,955
R-squared	0.756	0.756	0.741	0.756	0.741	0.768	0.763
collateral*time FE	✓	✓	✓	✓	✓	✓	✓
bank*fund type*time FE	✓	✓	✓	✓	✓	✓	✓
bank*FF FE	-	-	-	-	-	✓	✓
controls	✓	✓	✓	✓	✓	✓	✓

Note: This table reports the results of the regressions for alternative specifications of equation (13). Variable descriptions and summary statistics can be found in Table 3. The unit of observation is a contract between a fund and a bank reported as part of the disclosure of MMFs' portfolio holdings at month ends between February 2011 and June 2023. *rate* refers to the repo rate and is in basis points. *F MS bank repo* (*FF MS bank repo*) is the market share of the fund (fund family) in the repo market (see Eq. 11). *F MS treasury* (*FF MS treasury*) is the market share of the fund (fund family) in the T-bill market (see Eq. 12). *F bargaining power* (*FF bargaining power*) measures a fund's (fund family's) bargaining power vis-a-vis a bank in the repo market. The variables are in percentage points. *Amihud* is the Amihud liquidity index, where a higher value indicates lower liquidity. It is standardized to a mean of zero and a standard deviation of one. Standard errors are clustered at the fund level. Source: Crane Data. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The negative coefficient on the interaction term, significant at the 10% level, supports the model prediction.

Columns (3)–(7) use different measures of funds' market power. Column (3) uses fund family market shares in the repo (*FF MS bank repo*) and T-bill market (*FF MS treasury*) instead of fund market shares, which accounts for the possibility that negotiations with banks take place at the fund family level. We obtain qualitatively similar results to column (2). Columns (4) and (5) replicate columns (2) and (3) but use *F bargaining power repo* and *FF bargaining power repo* instead of funds' or fund families' market share in the repo market, again delivering results consistent with our predictions. Finally, columns (6) and (7) confirm these findings when we include fund family*bank fixed effects to further account for relationships between a fund family and a bank.

Results in Table 4 are consistent with Predictions 2 & 3 of our model.

5.3 MMF portfolio allocation between T-bills and the RRP facility

Next, we turn to the prediction that funds with a higher residual cash share allocate more to the RRP relative to T-bills, especially when Treasury market liquidity is low (Prediction 4). To test this prediction, we estimate regressions at the fund f-month t level:

$$\begin{aligned} RRP\ share_{f,t} = {} & \delta_1\ F\ residual\ cash\ share_{f,t} + \\ & \delta_2\ F\ residual\ cash\ share_{f,t} \times Amihud_t + controls_{f,t} + \phi_f + \theta_t + \varepsilon_{f,t}. \end{aligned} \tag{14}$$

The dependent variable $RRP\ share_{f,t}$ is the share of cash left over from repo lending allocated to the RRP as opposed to T-bills for fund f at time t. The explanatory variable $F\ residual\ cash\ share_{f,t}$ denotes fund f's residual cash share in time t. The variable $Amihud_t$ is the Amihud liquidity measure for T-bills. To account for time-varying factors that affect all funds, the baseline regression includes time-fixed effects (θ_t), but we progressively saturate the regressions with more demanding fixed effects and control variables. Standard errors are clustered at the fund level. We expect that funds with greater market power in the T-bill market allocate a greater share of their assets to RRP ($\delta_1 > 0$), and more so when liquidity conditions in the Treasury market are worse ($\delta_2 > 0$).

Table 5 shows results consistent with our hypotheses. Column (1) shows a positive and statistically significant coefficient on funds' *residual cash share*. This pattern suggests that funds allocate relatively more of their assets towards the RRP when their residual cash share is higher. Column (2) reports a positive coefficient on the interaction term between *F residual cash share* with *Amihud*, significant at the 1% level. These results suggest that funds with a higher residual cash share tilt their portfolio allocation between T-bills and the RRP towards the RRP more when the treasury market is illiquid. (The coefficient on *Amihud* is absorbed by time-fixed effects.)

Table 5: Treasury market liquidity and funds allocated to the RRP

	(1)	(2)	(3)	(4)	(5)
VARIABLES	RRP share	RRP share	RRP share	RRP share	Δ RRP share
F residual cash share	0.568***	0.562***	0.599***	0.509***	0.227***
	(0.027)	(0.027)	(0.027)	(0.031)	(0.022)
F residual cash share × Amihud		0.051***	0.058***		
		(0.008)	(0.010)		
F residual cash share × debt ceiling				0.074**	
				(0.029)	
F residual cash share × Δ Amihud					0.011*
					(0.007)
Observations	13,777	13,777	12,619	12,619	12,528
R-squared	0.703	0.705	0.751	0.747	0.269
time FE	✓	✓	-	-	-
fund FE	✓	✓	✓	✓	✓
fund type*time FE	-	-	✓	✓	✓
controls	-	-	✓	✓	✓

Note: This table reports the results for regression equation (14). Variable descriptions and summary statistics can be found in Table 3. Observations are at the fund-time level constructed from the holding level data reported as part of the disclosure of MMFs' portfolio holdings at month ends between the introduction of the RRP facility in September 2013 and June 2023. *F residual cash share* measures fund f's residual cash share, and *Amihud* is the Amihud measure of illiquidity (higher values correspond to lower liquidity in the Treasury market). It is standardized to a mean of zero and a standard deviation of one. Column (4) uses a dummy for debt ceiling episodes as a measure of liquidity, while column (5) reports results for a regression in changes. Standard errors are clustered at the fund level. *** p<0.01, ** p<0.05, * p<0.1. Source: Crane Data.

To tighten identification, column (3) 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 assets under management and interaction terms of *F residual cash share* with the 1-month T-bill rate and the federal funds rate. The sign, size, and significance of our coefficients of interest remain similar to column (2). This finding suggests that the predicted relationship between funds' residual cash share, liquidity, and the RRP share is not due to unobservable fund characteristics, time-varying shocks that affect different fund types, nor changes in assets under management, nor reflecting changes in the Fed funds rate or T-bill rate that could affect funds with different market shares differentially.

Column (4) uses a dummy for debt ceiling episodes as an alternative indicator of liquidity in the treasury market and confirms that funds invest relatively more in the RRP during periods when liquidity in the treasury market is low. Finally, column (5) reports results for Equation (14), but with the dependent variable and the liquidity index in changes. Again, we obtain qualitatively similar results.

These findings show that MMFs with a higher residual cash share tilt their portfolio towards the RRP, particularly when liquidity in the T-bill market is low. Table 5 thus provides empirical support for Prediction 4.

6 Intermediation frictions, market liquidity, and the measurement of the liquidity premium of T-bills

Market participants are typically willing to pay for the liquidity service flow provided by near-money assets. This premium, commonly referred to as liquidity premium, which forms part of the "convenience yield", is often measured as the difference between the prices of two securities that have identical characteristics except their liquidity.

The liquidity premium commanded by T-bills is usually computed as the spread between the 1- (or 3-) month GC repo rate and the T-bill rate (e.g. Duffee, 1996; Longstaff, 2004; Nagel, 2016). The intuition is that a 1-month repo contract collateralized by US Treasuries is considered as safe as a T-bill but, unlike a T-bill, cannot be liquidated before maturity.[31] Previous literature has shown that this measure of the liquidity premium is affected by the level of the federal funds rate (Nagel, 2016) and the supply of T-bills (Krishnamurthy and Vissing-Jorgensen, 2015), in particular since the great financial crisis (d'Avernas and Vandeweyer, 2023).

[31] Other measures of the liquidity premium also subtract the T-bill rates from alternative rates, which have similar safety properties but different liquidity properties. Therefore, our arguments also apply to other measures.

Such measures of the liquidity premium implicitly assume negligible intermediation frictions and a highly liquid T-bill market. However, our theoretical and empirical results suggest that MMFs have an impact on T-bill rates through their purchases, especially when T-bill markets are less liquid. MMFs' portfolio allocation could, in turn, also affect the liquidity premium measured by the GC repo and T-bill spread. If so, the GC-Tbill spread might not only capture investor preferences for liquidity but also reflect intermediation frictions and market illiquidity, which would have important implications for the interpretation of this measure as a liquidity premium. In fact, Proposition 3.6 implies that, in our model setting, T-bills can, at times, command an illiquidity premium: Their yields drop (prices increase) when the market is less liquid.

In Table 6, we show that funds' residual cash share indeed has a significant impact on the liquidity premium of T-bills. We estimate Equation (9) with the 1-month GC repo-Tbill spread as the dependent variable. Column (1) first shows that factors traditionally identified as affecting the liquidity premium do so also in our sample: the Fed funds rate enters with a positive sign, while the supply of T-bills enters with a negative sign. When we add the *residual cash share* in column (2), we find that it positively correlates with the liquidity premium, significant at the 10% level. Column (3) presents 2SLS results with %Δ *Euro repo* as IV and shows a positive and highly significant effect of the residual cash share on the liquidity premium. These results suggest that MMFs' portfolio allocation affects the liquidity premium. In terms of magnitudes, the partial impact of a one standard deviation increase in *residual cash share* on the GC repo-Tbill spread is equivalent to the effect of a 1 percentage point rise in the federal funds rate or a fifth of a percent decrease in the bills-to-GDP ratio. The effect of MMFs' portfolio allocation on the measured liquidity premium is, hence, economically meaningful.

To investigate the effect of MMFs on the liquidity premium further, we decompose the GC repo-Tbill spread into the GC-RRP and the RRP-Tbill spreads. MMFs are key investors in both T-bills and the RRP facility but not in the GC repo market. If MMFs' portfolio allocation drives the liquidity premium, we thus expect the residual cash share to affect the RRP-Tbill spread but not the GC repo-RRP spread. Column (4) shows that the effect of the residual cash share indeed operates through the RRP-T-bill spread (as already shown in Table 2), while column (5) shows

Table 6: MMFs' residual cash share and the liquidity premium

VARIABLES	(1) OLS GC-Tbill	(2) OLS GC-Tbill	(3) 2SLS GC-Tbill	(4) 2SLS RRP-Tbill	(5) 2SLS GC-RRP
residual cash share		0.10*	0.30***	0.32***	-0.02
		(0.06)	(0.09)	(0.12)	(0.14)
FFR	3.32***	2.94**	6.19***	2.39	3.80
	(1.09)	(1.32)	(1.47)	(4.06)	(4.42)
log(bills to GDP)	-18.76***	-22.37***	-31.88***	-12.57***	-19.31***
	(3.91)	(4.75)	(5.12)	(3.80)	(6.66)
VIX	0.23	0.21	0.33***	-0.12	0.45
	(0.16)	(0.14)	(0.12)	(0.35)	(0.44)
Observations	143	143	48	48	48
R-squared	0.31	0.34			
Anderson-Rubin test (p-val)			0.00	0.01	0.87
F stat			26.99	18.78	24.82

Note: This table reports results for Equation (9). Variable descriptions and summary statistics can be found in Table 1. Data are at a monthly frequency between February 2011 and December 2022. Columns (1) and (2) report the results of OLS regressions. Columns (3) to (5) report the 2SLS regressions in which %Δ *Euro repo* instruments *residual cash share*. The dependent variable is the GC-Tbill spread (liquidity premium) in columns (1) to (3), the RRP-Tbill spread in column (4), and the GC-RRP spread in Column (5). Wherever applicable, we report the p-value of the Anderson-Rubin test and the effective F statistic of the first stage as in Olea and Pflueger (2013). 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.

that its effect on the GC-RRP spread is statistically and economically insignificant, as expected. This insignificant result also suggests that our finding on the impact of European withdrawal from repo markets at quarter-ends operates through MMFs in the T-bill market and not through the GC repo market.

Figure 4 illustrates the relative importance of the RRP-Tbill and GC repo-RRP spreads in the evolution of the liquidity premium. The black line shows the liquidity premium, measured as the GC repo-Tbill spread, while the gray and blue bars show the relative contributions of the GC-RRP and RRP-Tbill spreads.

Even though the RRP facility is safer and more liquid than T-bills,[32] the sign of the RRP-Tbill spread oscillates. Moves in each direction have been large, at times exceeding 100 basis points. A negative spread is intuitive, given the superior safety and liquidity of the RRP facility compared to T-bills. A case in point is the March 2020 dash-for-cash episode, when the spread has fallen into deeply negative territory. However, a positive spread is harder to reconcile with a preference for liquidity. While there are possible explanations for why T-bills could be more convenient to hold than the RRP,[33] the spread is often too large for these explanations to plausibly account for it fully. Our theory and empirical analysis suggest that frictions in the money market funds sector, together with illiquidity in the T-bill market, can push up the RRP-Tbill spread through funds' price impact in the T-bill market.

The large movements in the RRP-Tbill spread, together with the results in Table 6 and positive MMF holdings of T-bills throughout the sample period, suggest that MMF intermediation frictions could be an important component of the measured liquidity premium.[34] For example, since 2022, the RRP-Tbill spread has been positive and large and accounts for the lion's share of the GC-Tbill spread. Consistent with our theoretical framework, this period coincides with a deterioration of liquidity conditions in the T-bill market.

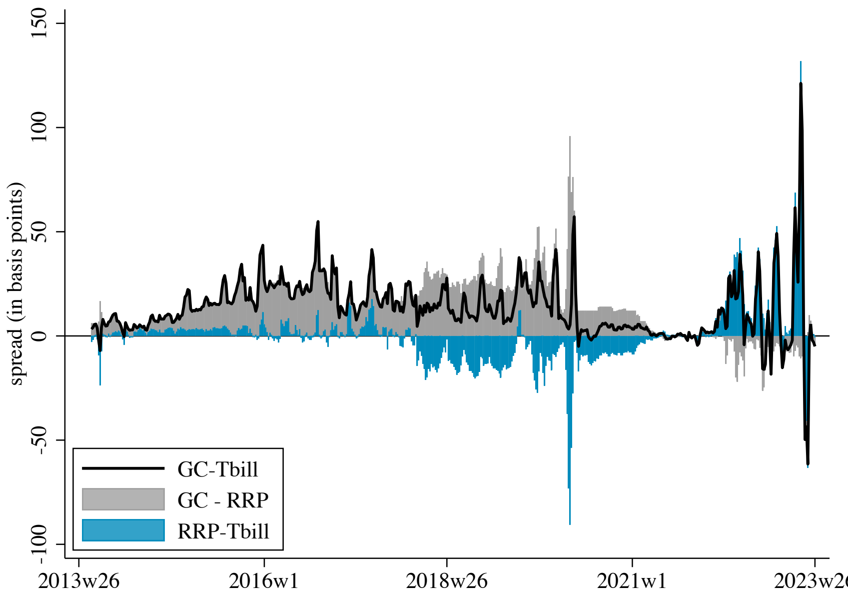
All in all, the discussion in this section suggests that part of what is commonly measured as liquidity premium could reflect not only investors' preference for liquidity but also intermediation frictions in the MMF sector. The visual evidence in Figure 4 indicates that at times of illiquidity

[32] It is safer because the Federal Reserve is the direct counterparty, and investments do not carry a risk of technical default when the government hits its debt ceiling. It is more liquid as it is an overnight instrument. Moreover, it pays an interest rate, which is administered by the Federal Reserve and moves in lock step with other policy rates.

[33] One possible explanation could be the existence of counterparty limits for the RRP facility, which makes MMFs reluctant to invest in the RRP facility. However, all MMFs are comfortable below the counterparty limits in our dataset. Another potential explanation could be the inconvenience of rolling over the RRP investments due to the fact that the RRP facility is overnight. However, it is unlikely to match the quantitatively large spread.

[34] While MMFs have access to both the RRP facility and T-bills, not all market participants can access the RRP facility. Therefore, their preference for liquidity could, in principle, also drive the lower T-bill rates. However, MMFs not arbitraging this difference is consistent with the existence of intermediation frictions.

Figure 4: Decomposing the liquidity premium



Notes: This figure plots the liquidity premium (black line, measured as the spread between the 1-month GC repo rate and 1-month T-bill rate), as well as the GC repo-RRP spread (gray bars) and RRP-Tbill spread (blue bars). The sum of the gray and blue bars adds up to the black line. Source: Crane Data.

in the T-bill market, variations in the RRP-Tbill spread because of intermediation frictions could drive a sizeable part of the liquidity premium as commonly measured in the literature.

7 Policy implications and conclusion

Our results illustrate why considering intermediation frictions in the MMF sector and market liquidity in the T-bill market are important to understanding the pricing of near-money assets and the observed time-variation in the liquidity premium of T-bills. These findings have implications for the transmission of monetary policy, government debt issuance, and the regulation of MMFs.

MMFs typically receive inflows during episodes of monetary tightening (e.g. Duffie and Krishnamurthy, 2016; Drechsler, Savov and Schnabl, 2017; Xiao, 2020). Our results suggest that these inflows could put downward pressure on both T-bill rates and repo rates through MMFs' price impact, weakening the transmission of monetary policy. Our framework yields two additional novel insights. First, illiquid Treasury markets exacerbate these concerns. Second, a larger central bank balance sheet, which allows flexible use of the RRP by MMFs (and potentially other participants) to alleviate their trade-offs, could mitigate this channel and hence improve the transmission of monetary policy. Moreover, our results highlight liquidity conditions in the T-bill market as an important factor for the transmission of monetary policy.

Our analysis also helps understand developments at the short end of the yield curve, with implications for government debt issuance. In the presence of the frictions identified in our analysis, higher government issuance could reduce supply-demand imbalances and allow the government to borrow at more favorable rates, in particular at times of illiquidity in the T-bill market. Moreover, to the extent that lower short-term rates incentivize the issuance of risky private short-term debt, with potential consequences for financial stability (see Greenwood, Hanson and Stein, 2015), the severity of intermediation frictions in the MMF sector could influence optimal government debt issuance and maturity.

Finally, our results inform policy on the regulation of the MMF sector. The MMF reform in 2016 has increased concentration in the MMF sector (Aldasoro, Ehlers and Eren, 2022). Higher market concentration, in particular in the repo market, can exacerbate the trade-offs highlighted in our analysis. For example, the reform resulted in a shift from prime to government money market funds. Government funds are more limited in the set of instruments they are allowed to hold. As a result, large inflows (e.g., during flight-to-quality or tightening episodes) could worsen supply-demand imbalances, including in the T-bill market. Our results highlight a trade-off for policymakers between improving the resilience of the MMF sector and possibly exacerbating market inefficiencies through higher market concentration.

In light of our findings, several open avenues for further research exist. A deeper quantitative analysis of the contribution of intermediation frictions and market illiquidity to the liquidity premium is one promising area. Studies digging deeper into the impact of these frictions on the transmission of monetary policy and how MMF regulations impact the pricing of near-money assets and other important macroeconomic variables in a general equilibrium setting could also be policy-relevant. Finally, the key insights of our framework regarding how strategic agents behave in multiple markets can also be applied to other markets.

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A Appendix to "Money-market funds and the pricing of near-money assets"

A.1 Additional figures and tables

This section provides additional figures and tables to support our analysis.

- Figure A1: There is no correlation between the quarter-to-quarter change in European banks' repo activity with US MMF and the quarter-to-quarter change in foreign banks' holdings of short-term treasuries. This zero correlation suggests that European banks' change in the demand for repos is uncorrelated with their demand for T-bills at quarter-ends, supporting the validity of our instrument.

- Figure A2 shows the quarter-end contraction in European banks' repo activity during our sample period.

- Figure A3: As discussed in the text, the MMF reform in 2016 significantly increased the HHI (ie market concentration) in the MMF sector (see Figure A3(b)). However, as shown in Figure A3(a), the correlation between *HHI bank repo* and *residual cash share* is positive and significant both in the pre- and post-reform period.

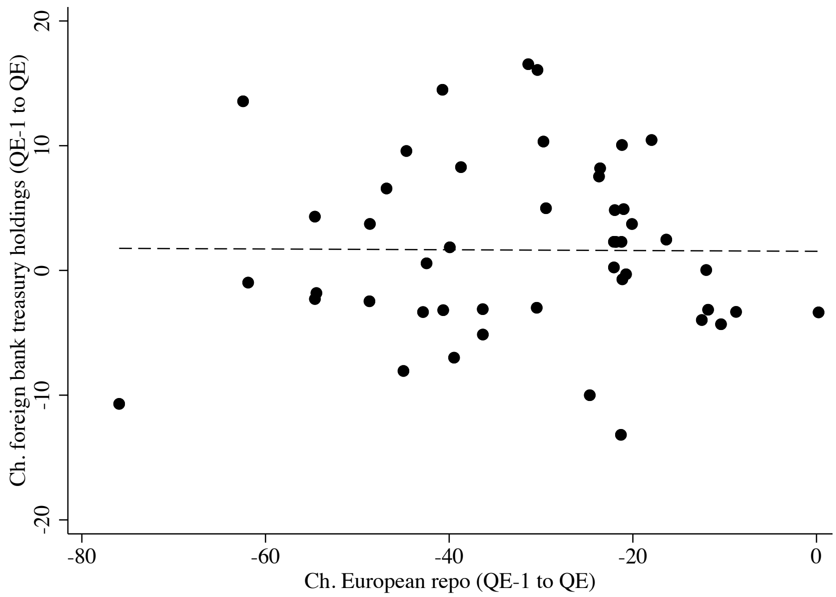
- Table A1: This table reports additional robustness checks and additional tests with the alternative instrumental variable. All regressions report 2SLS results for Equations (9) and (10). The dependent variable is the RRP-Tbill spread. Columns (1) and (2) show that controlling for the quarter-end change in foreign banks' demand for Treasuries does not affect our coefficient of interest. This finding suggests that any change in European banks' demand for T-bills is orthogonal to changes in their demand for repos with US MMFs, supporting our exclusion restriction. Columns (3) to (5) use the market concentration of MMFs in the repo market as an instrument for $residual\ cash\ share_t$. Column (3) confirms a positive causal effect of the residual cash share on the RRP-Tbill spread. Column (4) finds this effect to be present also in the post-MMF reform period (see discussion on Figure A3), while column (5) shows that the effect remains significant when we control for the share of government funds. Column (6) uses both %Δ *Euro repo* and *HHI bank repo* as instruments. The (robust) Hansen's J-test statistic has a p-value of 0.29, suggesting that the overidentifying restrictions are valid.

- Table A2: Baseline results (see Table 2) are similar when we used the log of total residual cash over GDP as an explanatory variable in Equation (9). Columns (1) and (2) report the results of OLS regressions, while columns (3) and (4) report the second stage of a 2SLS regression, in which we use %Δ *Euro repo* as IV. *Amihud* denotes the Amihud liquidity index, standardized to a mean of zero and standard deviation of one. Greater residual cash as a share of GDP increases the RRP-Tbill spread, especially when market liquidity is low.

- Table A3: Baseline results (see Table 2) are similar when we used the expected, rather than the realized, RRP-Tbill spread as the dependent variable. The table reports results for Equation (9) with the *expected* RRP-Tbill spread as the dependent variable. Columns (1) and (2) report the results of OLS regressions. Columns (3) and (4) report the second stage of a 2SLS regression, in which we use %Δ *Euro repo* as IV. *Amihud* denotes the Amihud liquidity index, standardized to a mean of zero and standard deviation of one. A greater residual cash share increases the expected spread and does so by more when market liquidity is low.

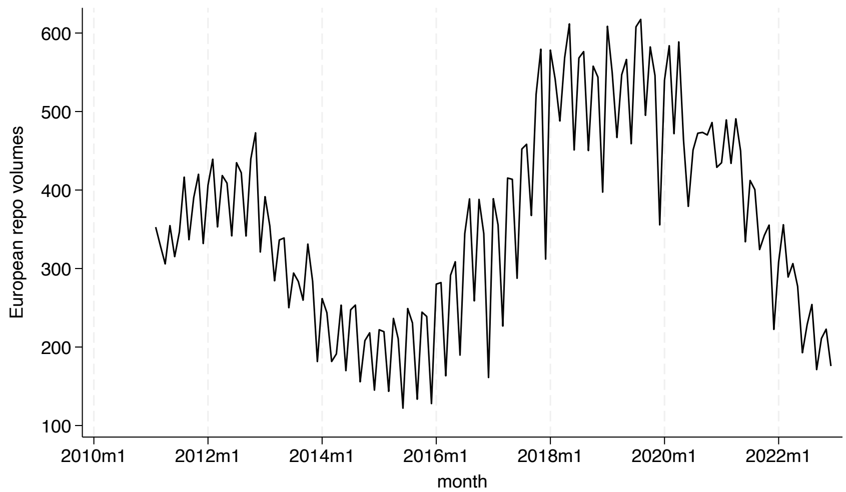
- Table A4: This table shows that our findings are robust to the use of alternative liquidity indicators. The table reports OLS and 2SLS results for Equation (9). The dependent variable is the RRP-Tbill spread in 2SLS regressions. Each exercise uses %Δ *Euro repo* as IV for the residual cash share but uses different (il)liquidity indicators. Columns (1) and (2) report the results of OLS and 2SLS regressions with the baseline Amihud index. Columns (3) and (4) report the results of OLS and 2SLS regressions with an indicator that takes on a value of one if the Amihud index lies in top tercile of the distribution and zero otherwise. Columns (5) and (6) report the results of OLS regressions with the bid-ask spread (1M) and an indicator that takes on a value of one if the bid-ask spread lies in top tercile of the distribution. Finally, column (7) uses the bid-ask spread (1M) as an IV for the Amihud liquidity index. Across specifications, the residual cash share has a positive effect on the RRP-Tbill spread, and the effect is stronger when liquidity is low.

Figure A1: The demand for repos by European banks and foreign banks' holdings of T-bills



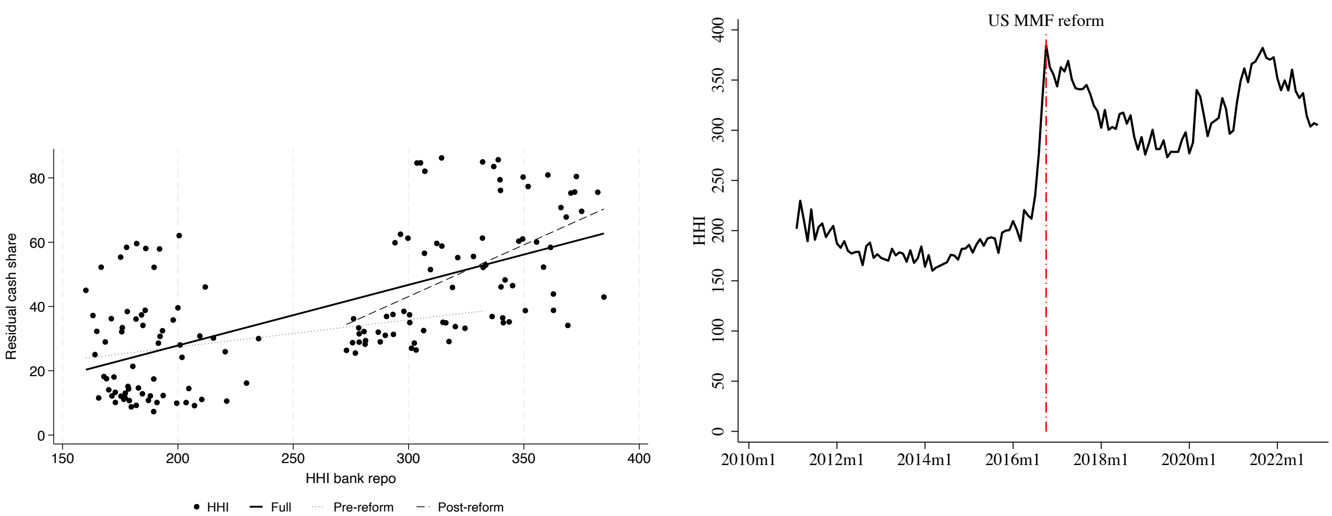
Notes: This figure plots the correlation between the quarter-to-quarter change in European banks' repo activity with US MMF and the quarter-to-quarter change in foreign banks' holdings of short-term treasuries.

Figure A2: European banks' repo activity



Notes: This figure plots total repo holdings by European banks at a monthly frequency over our sample period.

Figure A3: HHI for funds in the repo market and residual cash share



(a) HHI and residual cash share correlation

(b) HHI of the repo market

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). The variable $residual\ cash\ share_t$ 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.

Table A1: IV regressions – robustness and alternative IV

	(1)	(2)	(3)	(4)	(5)	(6)
	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
			HHI	HHI post	HHI post	EU+HHI
VARIABLES	RRP-Tbill	RRP-Tbill	RRP-Tbill	RRP-Tbill	RRP-Tbill	RRP-Tbill
residual cash share	0.33***	0.32***	0.25***	0.71***	0.54*	0.29***
	(0.12)	(0.05)	(0.08)	(0.08)	(0.32)	(0.10)
Amihud		-22.35***				
		(4.84)				
residual cash share × Amihud		0.47***				
		(0.11)				
%Δ foreign banks' treasury (quarter-end)	0.18	0.04				
	(0.15)	(0.11)				
share gov funds					0.90	
					(1.47)	
FFR	2.54	-3.14*	-0.88	1.30	3.08	2.52
	(4.01)	(1.88)	(2.91)	(1.19)	(3.91)	(4.23)
log(bills to GDP)	-12.59***	-5.19***	-15.20***	-19.02***	-12.90	-11.65***
	(3.81)	(1.49)	(4.13)	(6.71)	(14.07)	(3.38)
VIX	-0.10	-0.41**	0.03	-0.41**	-0.39*	-0.12
	(0.32)	(0.17)	(0.32)	(0.19)	(0.22)	(0.35)
Observations	48	48	143	75	75	48
Anderson-Rubin test (p-val)	0.00	0.05	0.01	0.00	0.32	0.02
F stat	16.60	3.29	9.62	47.12	4.19	4.35
IV Confidence set 1		[0.23; 0.52]				
IV Confidence set 2		[0.38; 1.25]				
Hansen J-stat (p)						0.29

Note: This table reports 2SLS results of regression equations (9) and (10). The dependent variable is the RRP-Tbill spread. Columns (1) and (2) use %Δ *Euro repo* as instrument for *residual cash share* and control for the quarter-end change in foreign banks' demand for Treasuries. *Amihud* denotes the Amihud liquidity index, standardized to a mean of zero and standard deviation of one. Columns (3)–(5) use *HHI bank repo* as instrument for *residual cash share*. Column (3) reports results for the full sample, while columns (4) and (5) restrict the sample to the months after the MMF reform in October 2016, whereas column (5) controls for the market share of government funds. Column (6) uses %Δ *Euro repo* and *HHI bank repo* as instruments. Data are at a monthly frequency between February 2011 and December 2022. Wherever applicable, we report the p-value of the Anderson-Rubin test and the effective F statistic as in Olea and Pflueger (2013). 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.

Table A2: Residual cash share to GDP

	(1)	(2)	(3)	(4)
	OLS	OLS	2SLS	2SLS
VARIABLES	RRP-Tbill	RRP-Tbill	RRP-Tbill	RRP-Tbill
log(residual cash to GDP)	6.88***	7.41***	8.21**	13.37***
	(2.12)	(1.67)	(3.43)	(3.81)
Amihud		20.66***		94.82*
		(4.59)		(48.96)
log(residual cash to GDP) × Amihud		6.15***		28.34**
		(1.72)		(13.78)
FFR	-2.20	-3.56	1.02	-3.52
	(3.04)	(2.38)	(4.74)	(3.89)
log(bills to GDP)	-21.08***	-16.13***	-19.04***	-4.34
	(4.99)	(3.42)	(5.78)	(11.95)
VIX	0.07	-0.21	-0.12	-1.05
	(0.37)	(0.24)	(0.41)	(0.70)
Observations	143	143	48	48
R-squared	0.25	0.43		
Anderson-Rubin test (p-val)			0.01	0.01
F stat			15.80	4.95
IV Confidence set 1				[8.16; 61.22]
IV Confidence set 2				[18.06; 32.11]

Note: This table reports results for Equation (9). Variable descriptions and summary statistics can be found in Table 1. Data are at a monthly frequency between February 2011 and December 2022. The dependent variable is the RRP-Tbill spread. The main independent variable is the log of the residual cash to GDP. Columns (1) and (2) report the results of OLS regressions. Columns (3) and (4) report the second stage of a 2SLS regression, in which we use %Δ *Euro repo* as IV. *Amihud* denotes the Amihud liquidity index, standardized to a mean of zero and standard deviation of one. Columns (3) and (4) restrict the sample to quarter-end months. Wherever applicable, we report the p-value of the Anderson-Rubin test and the effective F statistic as in Olea and Pflueger (2013). Column (4) reports weak-instrument robust 95% confidence sets for our estimates. 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.

Table A3: MMFs' residual cash share and the *expected* RRP-T-bill spread

	(1)	(2)	(3)	(4)
	OLS	OLS	2SLS	2SLS
VARIABLES	exp RRP-Tbill	exp RRP-Tbill	exp RRP-Tbill	exp RRP-Tbill
residual cash share	0.38***	0.33***	0.33***	0.32***
	(0.09)	(0.04)	(0.11)	(0.05)
Amihud		-10.26***		-18.69***
		(1.58)		(5.28)
residual cash share × Amihud		0.29***		0.41***
		(0.04)		(0.12)
FFR	-1.91	-5.44***	1.22	-4.02**
	(2.19)	(0.98)	(4.00)	(1.97)
log(bills to GDP)	-21.73***	-10.45***	-15.42***	-7.77***
	(4.41)	(1.73)	(3.51)	(1.69)
VIX	0.13	-0.31	0.03	-0.29*
	(0.26)	(0.19)	(0.29)	(0.17)
Observations	143	143	48	48
R-squared	0.50	0.73		
Anderson-Rubin test (p-val)			0.00	0.04
F stat			18.78	3.55
IV Confidence set 1				[0.23; 0.43]
IV Confidence set 2				[0.19; 0.64]

Note: This table reports results for Equation (9). Variable descriptions and summary statistics can be found in Table 1. Data are at a monthly frequency between February 2011 and December 2022. The dependent variable is the *expected* RRP-Tbill spread. Columns (1) and (2) report the results of OLS regressions. Columns (3) and (4) report the second stage of a 2SLS regression, in which we use %Δ *Euro repo* as IV. *Amihud* denotes the Amihud liquidity index, standardized to a mean of zero and standard deviation of one. Columns (3) and (4) restrict the sample to quarter-end months. Wherever applicable, we report the p-value of the Anderson-Rubin test and the effective F statistic as in Olea and Pflueger (2013). Column (4) reports weak-instrument robust 95% confidence sets for our estimates. 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.

Table A4: Alternative liquidity indicators

VARIABLES	(1) OLS Amihud RRP-Tbill	(2) 2SLS Amihud RRP-Tbill	(3) OLS Amihud (3) RRP-Tbill	(4) 2SLS Amihud (3) RRP-Tbill	(5) OLS Bid-Ask RRP-Tbill	(6) OLS Bid-Ask (3) RRP-Tbill	(7) 2SLS Bid-Ask RRP-Tbill
residual cash share	0.33***	0.32***	0.17***	0.17*	0.06	0.17***	0.31***
	(0.04)	(0.05)	(0.04)	(0.09)	(0.04)	(0.05)	(0.08)
illiquidity	-14.52***	-22.42***	-17.52***	-19.55*	-12.21***	-19.81***	-29.73***
	(2.53)	(4.65)	(4.61)	(11.81)	(2.04)	(6.91)	(4.41)
residual cash share × illiquidity	0.35***	0.47***	0.50***	0.44*	0.20***	0.45***	0.65***
	(0.05)	(0.10)	(0.10)	(0.25)	(0.02)	(0.13)	(0.12)
FFR	-4.45***	-3.10*	-3.50***	0.97	-3.05***	-1.02	-5.88
	(1.01)	(1.77)	(1.34)	(2.83)	(1.00)	(1.64)	(4.17)
log(bills to GDP)	-9.28***	-5.38***	-11.39***	-8.18**	-14.01***	-20.42***	-0.56
	(1.94)	(1.48)	(2.09)	(3.47)	(2.36)	(5.03)	(9.19)
VIX	-0.38**	-0.41***	-0.24	-0.26	-0.16	-0.14	-0.62*
	(0.17)	(0.16)	(0.23)	(0.25)	(0.17)	(0.22)	(0.33)
Observations	143	48	143	48	143	143	48
Anderson-Rubin test (p-val)		0.05		0.01			0.00
F stat		3.32		5.59			45.48

Note: This table reports results for Equation (9) with different indicators of illiquidity in the T-bill market. Variable descriptions and summary statistics can be found in Table 1. Data are at a monthly frequency between February 2011 and December 2022. The dependent variable is the RRP-Tbill spread. Columns (1) and (2) report the results of OLS and 2SLS regressions with the baseline Amihud index and %Δ *Euro repo* as IV. Columns (3) and (4) report the results of OLS and 2SLS regressions with an indicator that takes on a value of one if the Amihud index lies in top tercile of the distribution and %Δ *Euro repo* as IV. Columns (5) and (6) report the results of OLS regressions with the bid-ask spread (1M) and an indicator that takes on a value of one if the bid-ask spread lies in top tercile of the distribution and %Δ *Euro repo* as IV. Finally, column (7) uses the bid-ask spread (1M) and %Δ *Euro repo* as IV for the Amihud liquidity index and the residual cash share. 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.

A.2 Proofs

Proposition A.1 (Optimal rates with imperfect competition) *The optimal rate satisfies*

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

Proof of Proposition A.1. 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 A.2 (Equilibrium in the repo market) *Suppose that* $w_f = w_f^*/F$, *where* w_f^* *are* *uniformly bounded. For simplicity, we normalize* $\sum_f w_f^* = F$.[35] *Define*

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

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

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

Proof of Propositions A.2 and 3.1. We have

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

[35] 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.

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

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

Substituting this gives

$$\begin{aligned}
O(F^{-3}) + r_f(b) \ &= \ r_*(b) \\
+ \ \frac{1}{\alpha_b+\xi-1} & \frac{\alpha_b\Big(r_*(b) \ + \ F^{-1} r_f^{(1)}(b) \ + \ F^{-2} r_f^{(2)}(b) \Big)^{-\alpha_b} w_f \Big(\Big(r_*(b) \ + \ F^{-1} r_f^{(1)}(b) \ + \ F^{-2} r_f^{(2)}(b) \Big) - \rho \Big)}{r_*(b)^{-\alpha_b} \ + \ \Gamma_*(b)^{(1)} F^{-1} \ + \ \Gamma_*(b)^{(2)} F^{-2}} \\
= \ r_*(b) \ + \ F^{-1} & \frac{1}{\alpha_b+\xi-1} \alpha_b r_*(b)^{-\alpha_b} \Big(1 \ - \ F^{-1} r_f^{(1)}(b) r_*(b)^{-1}\alpha_b \Big) w_f^* \Big(\Big(r_*(b) \ + \ F^{-1} r_f^{(1)}(b) \Big) - \rho \Big) \\
\times\, r_*(b)^{\alpha_b} & \Big(1 \ - \ r_*(b)^{\alpha_b} \Gamma_*(b)^{(1)} F^{-1} \Big) \\
= \ r_*(b) \ + \ F^{-1} & \frac{w_f^*\alpha_b}{\alpha_b+\xi-1} \Big(1 \ - \ F^{-1} r_f^{(1)}(b) r_*(b)^{-1}\alpha_b - r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)} F^{-1} \Big) \Big(\Big(r_*(b) \ + \ F^{-1} r_f^{(1)}(b) \Big) - \rho \Big) \\
= \ r_*(b) \ + \ F^{-1} & \frac{w_f^*\alpha_b}{\alpha_b+\xi-1} \Big((r_*(b) - \rho) \ + \ F^{-1} \Big(r_f^{(1)}(b) - (r_f^{(1)}(b) r_*(b)^{-1}\alpha_b + r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)})(r_*(b) - \rho) \Big) \Big) \\
= \ r_*(b) \ + \ F^{-1} & \frac{w_f^*\alpha_b}{\alpha_b+\xi-1} \Big((r_*(b) - \rho) \ + \ F^{-1} \Big(r_f^{(1)}(b) - (r_f^{(1)}(b) r_*(b)^{-1}\alpha_b + r_*(b)^{\alpha_b}\Gamma_*(b)^{(1)})(r_*(b) - \rho) \Big) \Big)
\end{aligned}$$

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,

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

Q.E.D.

A.3 Proofs for the T-Bill Market Equilibrium

By (3), the total payoff that the fund receives from its T-bill/RRP investments is given by

$$\begin{aligned} D_f^T(\rho)\rho \;+\; (\Delta_f - D_f^T(\rho))\rho_* \;&=\; D_f^T(\rho)(\rho-\rho_*) \;+\; \Delta_f\rho_* \\ &=\; \Big((a_*(f)+\lambda_*(f)(\rho-\rho_*))(\rho-\rho_*) \;+\; \rho_*\Big)\Delta_f \\ &=\; \widetilde{\rho}\,\Delta_f\,, \end{aligned} \tag{15}$$

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 (15) is the market clearing rate $\hat{\rho}$ satisfying (5). 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 (5). 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 (3). The following is true.

Proposition A.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 A.4 (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

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

where we have defined

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

and where

$$\Gamma_*(b)^{(1)} \;=\; -\alpha_b r_*(b)^{-1-\alpha_b}E[r_f^{(1)}(b)]\,, \tag{16}$$

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

By (3), 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 Propositions A.4, A.3. We have

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

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,

$$
\begin{aligned}
&\frac{\partial\hat{\rho}}{\partial r_f(u)} \\
&= \ \Xi_{-f} w_f \left(R_*^{\xi} \frac{-(\xi+\alpha_u) r_f(u)^{-\xi-\alpha_u-1}\Gamma_*(u) + \alpha_u w_f r_f(u)^{-\alpha_u-1} r_f(u)^{-\xi-\alpha_u}}{\Gamma_*(u)^2} \right) \\
&+ 2w_f^2 \frac{U_{-f} - a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3} \Big(\sum_b (R_*/r_*(b))^{\xi} \Big) \left(R_*^{\xi} \frac{-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1}\Gamma_*(u)}{\Gamma_*(u)^2} \right) + \ O(F^{-3}) \\
&= \ \Xi_{-f} w_f R_*^{\xi} \Big(-(\xi+\alpha_u) r_f(u)^{-\xi-\alpha_u-1} \Gamma_*(u)^{-1} + \alpha_u w_f r_*(u)^{-\alpha_u-1} r_*(u)^{-\xi-\alpha_u} \Gamma_*(u)^{-2} \Big) \\
&+ 2w_f^2 \frac{U_{-f} - a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3} \Big(\sum_b (R_*/r_*(b))^{\xi} \Big) \left(R_*^{\xi} \frac{-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1}\Gamma_*(u)}{\Gamma_*(u)^2} \right) + \ O(F^{-3}) \\
&= \ \Xi_{-f} w_f^* F^{-1} R_*^{\xi} \Big(-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1} (1-(\xi+\alpha_u+1) r_*(u)^{-1} r_f^{(1)} F^{-1}) r_*(u)^{\alpha_u} (1 - r_*(u)^{\alpha_u} \Gamma_*(u)^{(1)} F^{-1}) \\
&+ \alpha_u w_f^* F^{-1} r_*(u)^{-\alpha_u-1} r_*(u)^{-\xi-\alpha_u} r_*(u)^{2\alpha_u} \Big) \\
&+ 2(w_f^*)^2 F^{-2} \frac{U_{-f} - a_*(f)d_f}{(V_{-f}+\lambda_*(f)d_f)^3} \Big(\sum_b (R_*/r_*(b))^{\xi} \Big) \left(R_*^{\xi} \frac{-(\xi+\alpha_u) r_*(u)^{-\xi-\alpha_u-1}\Gamma_*(u)}{\Gamma_*(u)^2} \right) + \ O(F^{-3}) \\
&= \ -\Xi_{-f} w_f^* F^{-1} R_*^{\xi} (\xi+\alpha_u) r_*(u)^{-\xi-1} \\
&+ \ \Xi_{-f} w_f^* F^{-2} R_*^{\xi} r_*(u)^{-\xi-1} \Big((\xi+\alpha_u) \Big((\xi+\alpha_u+1) r_*(u)^{-1} r_f^{(1)} + r_*(u)^{\alpha_u} \Gamma_*(u)^{(1)} \Big) \ + \ \alpha_u w_f^* \Big) - \ Q_f^*(u) F^{-2}
\end{aligned}
\tag{17}
$$

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,

$$
\frac{\partial\hat{\rho}}{\partial r_f(u)} \ = \ \hat{\rho}^{(1)}_{r_f(u)} F^{-1} \ + \ \hat{\rho}^{(2)}_{r_f(u)} F^{-2} \ + \ O(F^{-3}), \tag{18}
$$

where, using that

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

with

$$\Gamma_*(b)^{(1)} \;=\; -\alpha_b r_*(b)^{-1-\alpha_b} E[r_f^{(1)}(b)]\,, \tag{19}$$

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 A.5 (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 A.5. 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 (17), 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 (17) and (18), 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,

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

Hence, by (19), 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

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

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

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

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

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

The proof of Proposition A.5 is complete. Q.E.D.

Proof of Proposition 3.3. The proof follows directly from Proposition A.5. Q.E.D.

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

Proposition A.6 (Equilibrium T-bill rate) *In equilibrium,*

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

where

$$
\begin{aligned}
&\hat{\rho}^{(1)} \\
&= -\mathcal{E}^{-1}\Bigg(\frac{\xi}{(\alpha+\xi)} \underbrace{E[\psi_f]}_{average\ passthrough} \Big(\frac{\alpha}{\alpha+\xi-1}(r_*(f)-\tilde{\rho}_f^*) \underbrace{H(W)}_{repo\ concentration} - \underbrace{E[w_f^*\Lambda_f\Delta_f^*]}_{price\ impact\ internalization}\Big) \\
&+ \underbrace{\mathrm{Cov}\Big(\psi_f, \frac{\alpha w_f^*}{\alpha+\xi-1}(r_*(f)-\tilde{\rho}_f^*) \; - \; w_f^*\Lambda_f\Delta_f^*\Big)}_{strategic\ interactions\ in\ the\ T-bill\ market}\Bigg)
\end{aligned}
$$

Proof of Proposition A.6. 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 (7). 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

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

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

$$\begin{aligned}
\widetilde{\rho}_f \;&=\; \Big((\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)(a_*(f) + \lambda_*(f)(\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)) + \rho_*\Big)\\
&=\; \rho_* \;+\; (\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)a_*(f)\\
&+\; (\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)^2\lambda_*(f)\\
&=\; \rho_* \;+\; (\hat{\rho}^* \;+\; \hat{\rho}^{(1)}F^{-1} \;+\; \hat{\rho}^{(2)}F^{-2} - \rho_*)a_*(f)\\
&+\; \Big((\hat{\rho}^* - \rho_*)^2 \;+\; 2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(1)}F^{-1} \;+\; 2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(2)}F^{-2} + (\hat{\rho}^{(1)})^2F^{-2}\Big)\lambda_*(f)\\
&=\; \widetilde{\rho}_f^* \;+\; 2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(1)}\lambda_*(f)F^{-1} \;+\; (2(\hat{\rho}^* - \rho_*)\hat{\rho}^{(2)} + (\hat{\rho}^{(1)})^2)\lambda_*(f)F^{-2} \;+\; O(F^{-3})
\end{aligned} \tag{20}$$

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

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

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

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

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

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

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_1 r_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_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) \\
&=\; (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_1 r_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)})^2 F^{-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_1 r_f^{(2)} + a_2\Gamma_*^{(2)}) F^{-2} \;+\; O(F^{-3})\,.
\end{aligned}
$$

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

$$\hat{\rho}^{(1)} \;=\; -(\lambda+\bar{\lambda})^{-1}(A_{1,1}r_f^{(1)} \;+\; A_{1,2}\Gamma_*^{(1)})$$

$$-\;(S-a-A)(\lambda+\bar{\lambda})^{-2}(C_{1,1}r_f^{(1)} \;+\; C_{1,2}\Gamma_*^{(1)})$$

$$r_f(u)^{(1)} \;=\; \frac{\alpha_u+\xi}{\alpha_u+\xi-1}\widetilde{\rho}_f^{(1)} \;+\; \frac{\alpha_u w_f^*}{\alpha_u+\xi-1}\left(1+\frac{\alpha_u w_f^*}{\alpha_u+\xi-1}F^{-1}\right)(r_*(u)-\widetilde{\rho}_f) \;-\; w_f^*\Lambda_f\Delta_f^*$$

$$\widetilde{\rho}_f \;=\; \widetilde{\rho}_f^* \;+\; 2(\hat{\rho}^*-\rho_*)\hat{\rho}^{(1)}\lambda_*(f)F^{-1} \;+\; (2(\hat{\rho}^*-\rho_*)\hat{\rho}^{(2)}+(\hat{\rho}^{(1)})^2)\lambda_*(f)F^{-2} \;+\; O(F^{-3})$$

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

$$A_{1,1} \;=\; (\alpha+\xi)r_*^{-\xi-1}R_*^{\xi}E[a_f]$$

$$A_{1,2} \;=\; R_*^{\xi}r_*^{-\xi}r_*^{\alpha}E[a_f]$$

$$C_{1,1} \;=\; (\alpha+\xi)r_*^{-\xi-1}R_*^{\xi}E[\lambda_f]$$

$$C_{1,2} \;=\; R_*^{\xi}r_*^{-\xi}r_*^{\alpha}E[\lambda_f]$$

where we have used (20) and (16).

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

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

The Proof of Proposition A.6 is complete. Q.E.D.

Proof of Proposition 3.4. The proof follows directly from Proposition A.6. Q.E.D.

A.4 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))

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

and hence (3) takes the form

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

so that we recover the upward-sloping demand curves (3), but the coefficients $a_*(f),\ \lambda_*(f)$ are endogenous, determined in equilibrium through the strategic interaction of funds in the T-bill market. Market clearing then implies

$$\sum_i \frac{\rho - \rho_* + \xi_f}{\gamma_f + \beta_f \Delta_f} \Delta_f \ = \ S\,,$$

so that

$$a + \lambda(\rho - \rho_*) \ + \ \sum_f (\rho - \rho_* + \xi_f) \frac{\Delta_f}{\gamma_f + \beta_f \Delta_f} \ = \ S \,,$$

so that

$$\rho \ = \ \rho_* \ - \ \bar{\xi} \ + \ \Lambda(S - a), \ \bar{\xi} \ = \ \frac{\sum_f \xi_f \frac{\Delta_f}{\gamma_f + \beta_f \Delta_f}}{\lambda + \sum_f \frac{\Delta_f}{\gamma_f + \beta_f \Delta_f}}$$

and

$$\Lambda \ = \ \frac{1}{\lambda + \sum_f \frac{\Delta_f}{\gamma_f + \beta_f \Delta_f}} \,.$$

We will need the following characterization of this strategic interaction and equilibrium price impacts γ_f from Malamud and Rostek (2017).

Proposition A.7 *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 $b = b_0 + b_1 F + O(F^{-1})$ with

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

and

$$b_0 \ = \ - \sum_f (\beta_f \Delta_f)^{-2} / (F b_1) \,.$$

γ_f are increasing with respect to Δ_f in the cross-section, and all γ_f are decreasing in λ (the exogenous liquidity).

Proof of Proposition A.7. 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

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

so that

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

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.

Proof of Proposition 3.5. The proof follows directly from Proposition A.7. Q.E.D.