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

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Abstract

We introduce a new channel through which US money market funds (MMFs) affect the pricing of near-money assets and their convenience yields. We first build a parsimonious model that guides our empirical analysis. In the model, frictions in the MMF sector and the T-bill market impact the prices of T-bills and repos simultaneously. Using instrumental variables, we then establish that MMFs have an economically significant price impact in the T-bill market and that higher concentration in the MMF sector worsens this price impact. Funds internalize their price impact when setting repo rates and allocating portfolios between repos, T-bills and the Federal Reserve's RRP facility. Our results suggest that these frictions generate sizable variation in measured T-bill convenience yields. We discuss the implications for monetary policy transmission, government debt issuance, and MMF regulation.

Keywords: T-bills, repo, money market funds, near-money assets, liquidity, convenience yield
JEL Classification Numbers: E44, G11, G12, G23

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1 Introduction

US Treasury bills (T-bills) serve as the reference asset for global finance and pricing other assets. They command a convenience yield, which is typically measured as the rate differential between T-bills and assets that are either not as safe or not as liquid. It is often interpreted as the premium that investors are willing to pay for the safety or liquidity of T-bills. (e.g. Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood et al., 2015; Nagel, 2016; d'Avernas and Vandeweyer, 2023). Estimates of the size of the convenience yield on T-bills are large and vary substantially in magnitude, ranging from 73 basis points (Krishnamurthy and Vissing-Jorgensen, 2012) to 7.6% per year (Di Tella et al., 2023). Moreover, the equity premium puzzle has long been recognized as also presenting a risk-free rate puzzle (e.g. Weil, 1989): if investors require a large risk premium for holding equities, suggesting high intertemporal risk aversion, then why are T-bill rates so low?

Surprisingly, T-bills enjoy an economically significant convenience yield even against other near-money assets that are equally safe and liquid, if not more so. One such asset is the reverse repo facility (RRP) of the Federal Reserve, which allows investors to place funds overnight and receive an interest rate administered by the central bank. As an overnight liability of the central bank, it is free from liquidity risk, duration risk, and the risk of technical default during debt ceiling episodes. Despite these advantages, we document that the 1-month RRP rate has often exceeded the 1-month T-bill rate. Notably, in 2022, the RRP rate exceeded the T-bill rate by around 20 basis points on average, with a peak of around 170 basis points.

Our paper presents a mechanism that offers a novel explanation for why T-bill rates are so low or why T-bill convenience yields so high. It is based on frictions in the T-bill market and complementary to existing explanations based on investor preferences. In addition, we provide a comprehensive study of major markets for near-money assets: T-bills, the RRP facility, and repos between MMFs and banks.[1]

Our mechanism rests on the central role of US money market funds (MMFs) in these markets for

[1] For collateral providers (banks and the Federal Reserve), these transactions are called repurchase agreements or repos. For cash lenders (MMFs), they are called reverse repos.

near-money assets. MMFs are short-term investment vehicles with total assets under management (AUM) of about $7 trillion as of today, equal to over 20% of US GDP or total commercial bank assets. They use short-term safe and liquid assets, such as T-bills, the RRP facility, and reverse repos with banks as primary tools to manage their liquidity. MMFs comprise one-fifth of the T-bill market on average, and their holdings significantly co-move with the T-bill supply, highlighting their important role as marginal investors. Through repos, they are also among the most important suppliers of short-term funding to banks.

We show that MMFs have an economically sizeable and statistically significant price impact in the T-bill market: when MMFs purchase T-bills, they drive their prices up (and rates down). We provide evidence that these results are not merely driven by general equilibrium effects of many atomistic MMFs and concentration in the MMF sector increases the price impact of MMFs in the T-bill market. Moreover, MMFs internalize their price impact in the T-bill market and adjust their behavior in other markets. We find that funds with greater price impact in the T-bill market indeed set lower repo rates and shift their portfolio allocations away from T-bills. They do so by more when the T-bill market is less liquid. Our results illustrate that intermediation frictions in the MMF sector play an important role in understanding pricing of near-money assets and in particular explaining why T-bill rates are so low and measured convenience yields so high.

Our paper proceeds as follows. First, we present stylized facts about MMFs and major markets for near-money assets (i.e., T-bills, the RRP facility, and repos between MMFs and banks), highlighting the significance of MMFs in these markets and the concentrated nature of the sector. Second, building on these facts and to guide our empirical analysis, we build a simple theoretical model of MMFs' strategic interactions with each other and with banks in these markets. Third, we test the predictions of the model, thereby assessing the importance of intermediation frictions and liquidity conditions in the T-bill market for the pricing of near-money assets, including the convenience yield, and portfolio allocations of MMFs. Based on these results, we draw policy implications for monetary policy transmission, government debt issuance, and the regulation of MMFs.

We begin by documenting a set of stylized facts. First, we show that investments of MMFs in

T-bills, reverse repos, and the RRP facility are highly concentrated. The ten largest fund families account for 80% of the total investments in each of these instruments. Second, the market shares of fund families across markets feature a high correlation. For example, the correlation between funds' repo market share and T-bill market share is around 60%, even conditional on fund size. Third, when liquidity in the T-bill market is low, MMFs tend to allocate a larger fraction of their funds to the RRP facility compared to T-bills.

Based on these observations, we present a parsimonious model of interactions of MMFs with each other and with banks across markets. Funds manage their portfolios of near-money assets by investing in T-bills, reverse repos with banks, and the RRP facility. MMFs have a price impact in the T-bill market – if they buy more T-bills, the price increases, which can be motivated by the T-bill supply being finitely elastic. In the repo market, facing a downward-sloping demand curve from banks, funds optimally set repo rates. The model also allows MMFs to invest in the RRP facility at a rate administered by the Federal Reserve. We assume convex costs associated with investments in the RRP facility. In the presence of these costs, funds respond to interest rate differentials between T-bills and the RRP facility.[2]

The model yields several testable predictions. An important insight is that MMFs internalize their price impact and adjust their portfolio allocations *across* markets accordingly. A key variable in our analysis is the "residual cash share" of MMFs: the share of funds not invested in reverse repos with banks. The model predicts that a higher residual cash share has a negative effect on T-bill rates; hence, it has a positive effect on the RRP-Tbill spread. However, in the repo market, funds take into account their price impact in the T-bill market. When their T-bill price impact is greater, funds set lower repo rates to attract more repo demand from banks. As funds lend more to banks through reverse repos, their residual cash share decreases, which subsequently reduces their price impact in the T-bill market. The model also predicts that funds with a higher residual cash share favor investments in the RRP facility over T-bills. Similarly, funds favor the RRP facility during times of illiquidity in the T-bill market, when their price impact is larger.

[2]Such costs make interior solutions observed in the data more likely and empirically plausible. While explicitly microfounding these costs is beyond the scope of this paper, precautionary motives to stay away from the investment caps of the RRP facility could serve as an interpretation.

We test the predictions of the model using a detailed dataset of US MMFs' individual portfolio holdings. The dataset is obtained from regulatory filings and covers the near-universe of US MMFs. It provides detailed information on contract characteristics on each investment at a monthly frequency between February 2011 and June 2023.

Our first empirical result is that MMFs, on aggregate, have a price impact in the T-bill market and hence affect the RRP-Tbill spread. Guided by our theoretical model, we regress the 1-month RRP-Tbill spread on the residual cash share (the share of funds that are not invested in reverse repos with banks) and other standard macroeconomic control variables, such as the federal funds rate, T-bill supply, and the VIX (e.g. Nagel, 2016; d'Avernas and Vandeweyer, 2023). We obtain an economically and statistically significant positive coefficient in the regression of the RRP-Tbill spread on the residual cash share, consistent with MMF price impact in the T-bill market. Moreover, including the residual cash share in addition to standard macro controls increases the R^2 from 2% to 41%.

To identify the price impact of MMFs, we use an instrumental variable that exploits exogenous changes in the demand for repos by European banks due to "window dressing", including for regulatory purposes. We construct the instrument as the percentage change in the volume of repo transactions between US MMFs and European banks at quarter-ends. As we argue, this change in the demand for repos is exogenous to changes in the residual cash share. For the major part of our sample, European banks were allowed to report their Basel III leverage ratio based on a quarter-end snapshot of their balance sheet, as opposed to a measure based on the daily averages over the entire quarter. This allowed them to expand balance sheets outside of quarter-end dates without regulatory restrictions. European banks have used this extra balance sheet capacity to act as repo intermediaries, borrowing money from MMFs and lending it on to other counterparties with US Treasury collateral, such as hedge funds. Repo intermediation is balance sheet intensive but easy to scale back. Therefore, at quarter-ends, European banks sharply reduced the balance sheet-intensive repo intermediation in order to lower their leverage and comply with regulations or simply do window-dressing to reduce their balance sheet size temporarily (Aldasoro et al., 2022).

Importantly, the quarter-end retrenchment by European banks is determined by how much their global balance sheet has expanded during the full quarter and how much it needs to shrink to comply with regulations or for window-dressing purposes. It is hence unrelated to the prevailing conditions in the repo or T-bill market in the United States at quarter ends, nor does it reflect MMFs' behavior. We provide direct evidence that the withdrawal of European banks from the repo market is uncorrelated with their T-bill holdings as well as the T-bill holdings of other major market participants, such as primary dealers, hedge funds, and commercial banks. It is also uncorrelated with general economic conditions reflected by the return on the S&P 500 and the change in the 10-year yield. Furthermore, Correa et al. (2020) show that US Global Systemically Important Banks (GSIBs) increase their dollar liquidity provision in response to dollar funding shortages at quarter-ends, which is mainly financed by reducing excess reserves at the Federal Reserve. Therefore, their T-bill holdings are not affected. All this evidence supports the validity of the exclusion restriction.

Using the European repo demand shock as an instrument in two-stage least squares regressions, we find that a one standard deviation increase in the residual cash share (or 22%) leads to an almost seven basis point (bps) increase in the 1-month RRP-Tbill spread. The standard deviation in the RRP-Tbill spread is 10.7 bps, so the estimated effect is sizeable. Moreover, we find that this price impact intensifies during periods of T-bill market illiquidity, which is consistent with our model prediction and can help explain the puzzling positive RRP-Tbill spread we document. Supporting the relevance of our instrument, we find a strong first-stage relationship between the residual cash share and our instrument.

To further strengthen identification we exploit an additional feature of European banks' withdrawal from US repo markets. The withdrawal is concentrated in the few days at quarter-ends and rebounds quickly at the beginning of the next quarter (Munyan, 2017). We thus use daily data on T-bill rates and study the pricing of very short-term T-bills with a remaining maturity of a few days. We show that when the quarter-end withdrawal of European banks is larger and funds thus have more residual cash, the rates on very short-term T-bills fall by more also in higher-frequency regressions. Confirming our baseline results at higher-frequency helps address potential concerns that might arise at monthly frequency.

A concern is that MMFs' aggregate impact on T-bill rates could result from general equilibrium effects with many atomistic MMFs. To address this concern, we provide a set of theoretical and empirical results that show that fund concentration matters for the RRP-Tbill spreads, and funds internalize their price impact across markets, which supports that individual MMFs act strategically.

One important result of the model is that the aggregate price impact is greater if T-bill purchases are more concentrated, that is, if fewer funds buy the same total amount. The intuition is that funds' optimal allocation to T-bills reflects a trade-off between worsening T-bill pricing and avoiding costs of investing in the RRP facility. As each MMF becomes smaller, each fund's demand becomes more elastic. Aggregating across many such more elastic demands yields a flatter market demand curve for T-bills, so the T-bill yield needs to move less to absorb extra MMF demand in the presence of many atomistic MMFs. Empirically, we find that the positive effect of the residual cash share on the RRP-Tbill spread is indeed larger when purchases are more concentrated.

To provide further evidence that MMFs internalize their price impact in the T-bill market and act strategically, we exploit the granular nature of our dataset. In contract-level regressions, we show that funds with a higher market share in the T-bill market charge lower repo rates. Moreover, this effect is stronger when liquidity in the T-bill market is low. Both results are consistent with our model predictions and funds internalizing their price impact. Our granular data allow us to include a battery of time-varying fixed effects. These rule out alternative explanations arising from potential differences in the time-varying unobservable bank, instrument, or fund-type characteristics, as well as macroeconomic factors.

Finally, we provide fund-level evidence on the allocation of assets between T-bills and the RRP facility. We test the model prediction that funds allocate relatively more to the RRP facility when their residual cash share is higher, as well as when the T-bill market is less liquid. We find that this is robustly the case. This finding can rationalize the abrupt rise in the take-up of the RRP facility from almost zero to $2.5 trillion within months in 2022 as funds substituted their T-bills for the RRP facility as liquidity conditions in the T-bill market worsened.

Our findings offer a novel explanation of what drives T-bill rates and convenience yields in addition to existing preference-based explanations. For example, one common measure of the convenience yield is the 1-month General Collateral (GC) repo minus Tbill spread, which compares the rates on T-bills with those of an equally safe but less liquid asset (e.g. Nagel, 2016).[3] A higher GC repo - Tbill spread is usually interpreted as an increased investor preference for liquidity, i.e., the liquidity premium. However, through the lens of our model, a higher measured liquidity premium could also reflect a greater price impact of MMFs, especially when T-bill markets are less liquid. In fact, our model suggests that common measures of the convenience yield of T-bills increase when the T-bill market is less liquid. MMFs' price impact can thus amplify the impact of investor preferences on convenience yields.

We find that MMFs' residual cash share has an economically and statistically significant effect on the liquidity premium when measured as the GC repo - T-bill spread. A one standard deviation increase in the residual cash share (or 22%) on the GC repo-Tbill spread is equivalent to the effect of a one 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. This finding suggests that MMFs' portfolio allocation affects the liquidity premium through the T-bill market. A simple decomposition exercise suggests that the forces highlighted by our model – intermediation frictions, MMFs' strategic behavior, and liquidity conditions in the T-bill market – have driven a sizable part of the overall 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 et al., 2017). 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. This is especially so when the market for MMF T-bill purchases is more concentrated or liquidity conditions in the T-bill market are worse. A larger central bank balance sheet with greater availability of the

[3] 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.

RRP facility can partly offset this channel but not entirely undo it. Second, targeted government debt issuance could alleviate these supply-demand imbalances, improving liquidity and increasing government revenues. Third, reforms of the MMF sector that increase the demand for safety could incentivize MMFs to hold more T-bills or reforms that increase the concentration in the MMF sector (Aldasoro et al., 2022) could intensify their price impact in the T-bill market.

Related literature. A large literature investigates convenience yields 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.[4] Consequently, they find that the supply of T-bills affects this convenience yield. Greenwood et al. (2015) also show that investors derive monetary benefits from holding short-term securities issued both by the government and private intermediaries.[5] 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.[6] Focusing on the post-financial crisis 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. Cieslak et al. (2024) and Li et al. (2022) study the link between the convenience yield and inflation and inflation expectations, respectively. Focusing on European bonds, Corell, Mota and Papoutsi (2023) decompose convenience yields into liquidity, duration, risk-based value and collateral components.

Our analysis offers novel insights into the determinants of the liquidity premium/convenience yield on T-bills. We provide evidence that intermediation frictions in the money market fund

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

[5] 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 et al. (2019) tie the convenience yield on short-term bonds to demand by intermediaries to back inside money.

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

sector and their interaction with liquidity conditions in the T-bill market affect the pricing of near-money assets, such as T-bills and repos. Our results suggest that part of what is commonly attributed to the T-bill convenience yield reflects MMFs' portfolio allocation choice and their price impact. A decomposition exercise suggests that since 2022, intermediation frictions and T-bill market illiquidity have been important drivers of the T-bill convenience yield.

Our paper also sheds new light on the importance of MMFs in short-term money markets[7] as well as in the transmission of monetary policy through banks and non-bank lenders (e.g. Duffie and Krishnamurthy, 2016; Drechsler et al., 2017; Xiao, 2020). By jointly accounting for MMFs' optimal price setting and asset allocations between T-bills, the RRP, and reverse 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.[8] Huber (2023) finds that in certain segments of the repo markets, MMFs' preferences for stable lending and aversion to counterparty concentration give dealers market power, so dealers borrow at repo rates below their marginal value of intermediation and the ON RRP tempers these markdowns. Our results can provide a complementary mechanism for why MMFs prefer stable lending relationships. In contemporaneous work, Stein and Wallen (2025) also study the impact of intermediation frictions on the spread between the RRP and T-bills in a setup with perfectly competitive MMFs with heterogeneous preferences and corporate treasurers. In our setup, we can jointly trace the impact of strategic MMFs on repo markets, T-bill markets, and the RRP facility. Due to the different focus, the nature of the empirical tests and identification strategies also differ between their paper and ours. Moreover, 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 et al., 2020; Vissing-Jorgensen, 2021; Barth and Kahn, 2021; Eren and Wooldridge, 2021; He et al., 2022; d'Avernas et al., 2024).

[7] See Kacperczyk and Schnabl (2013); Chernenko and Sunderam (2014); Krishnamurthy et al. (2014); Copeland et al. (2014); Schmidt et al. (2016); Han and Nikolaou (2016); Eren et al. (2020a,b); Hu et al. (2021); Cipriani and La Spada (2021); Li (2021); Aldasoro et al. (2022); Anderson et al. (2022).

[8] See also Martin et al. (2019) and Infante (2020) for a discussion of the RRP and its impact on short-term markets.

Finally, our findings speak to the broader literature on intermediary asset pricing (e.g. Basak and Pavlova, 2013; He and Krishnamurthy, 2013; Brunnermeier and Sannikov, 2014; Adrian et al., 2014; He et al., 2017; Gromb and Vayanos, 2018; Siriwardane et al., 2022; Du et al., 2023). 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 on 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.

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.[9] 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.

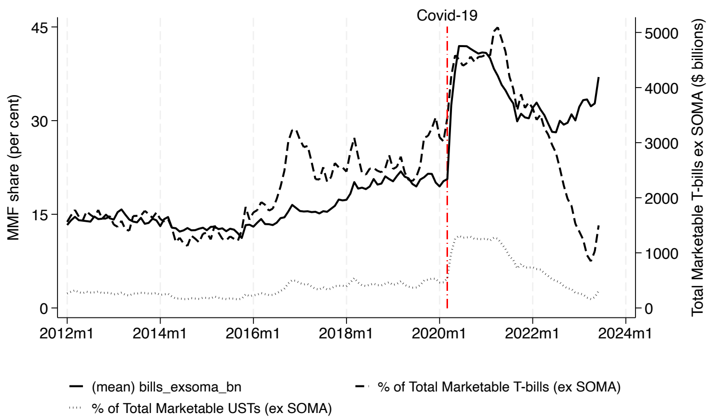
MMFs have a sizable share in markets for near-money assets, i.e., T-bills, the RRP facility, and reverse repos with banks (see Figure 1). Throughout the sample, on aggregate, MMFs' average market share in the T-bill market is 20%, with a peak of 45% during the Covid-19 crisis. Moreover, their holdings significantly co-move with the T-bill supply, suggesting an important role for MMFs as marginal investors in this market.[10] MMFs are the single largest investor group in the RRP facility, representing 89% of its usage since its inception in September 2013 (Afonso et al., 2022).

[9] 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 since they are close substitutes for liquidity management purposes. These investments in near-money assets amount to more than 50% of the total MMF assets under management. For more details on who borrows from MMFs, see also Aldasoro and Doerr (2023).

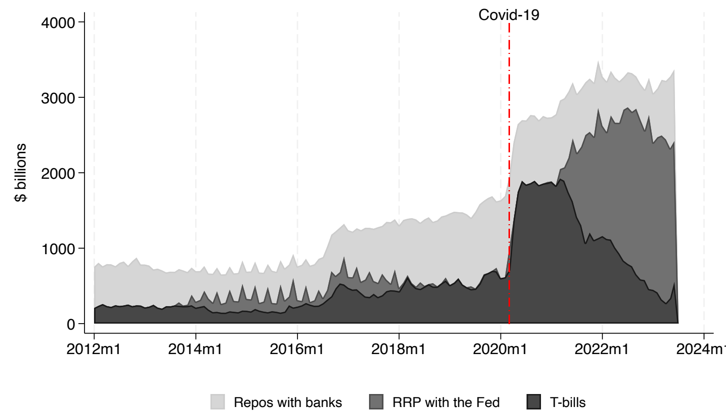
[10] A regression of changes in MMF T-bill holdings on changes in the T-bill supply (excluding holdings at the Fed's SOMA portfolio) yields a statistically significant (at 1%) coefficient of 0.45, suggesting that for every one unit of new T-bill issued, MMFs on average absorb 0.45.

They also 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.

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



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



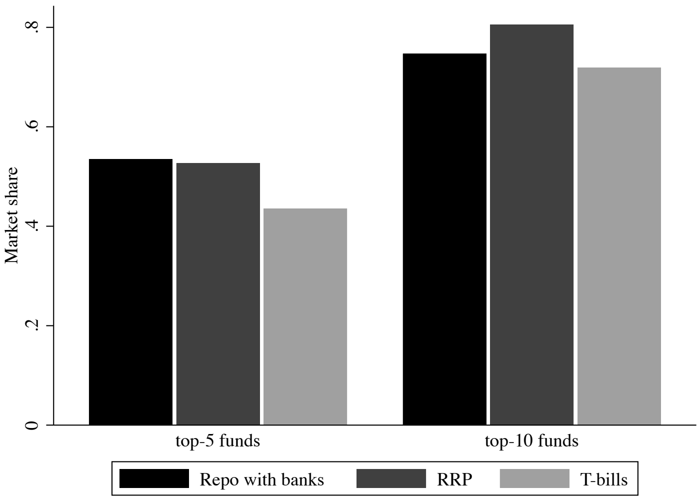
(b) MMFs' portfolio allocation between T-bills, repos, and the RRP varies over time

Note: 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 total MMF share of holdings. 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.

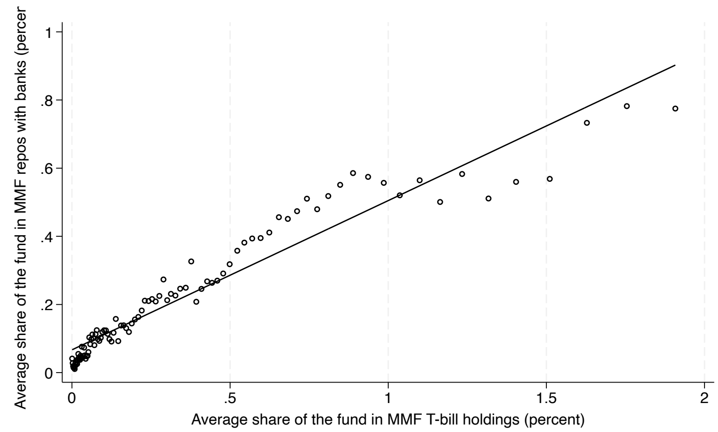
We document a significant concentration in the holdings of each instrument. For all three instruments that we focus on in this study, we find that the holdings of around ten fund families account for around 80% of the total (see Figure 2(a)). This concentration motivates our modeling choice of MMFs as large and strategic agents rather than atomistic price takers, as explained below.

Two other facts suggest linkages between different markets due to the strategic actions of MMFs. First, to a large extent, funds that are large players in one market are also large in the other markets. For example, 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(b)). This remains so even after we condition on size (unreported). Second, Figure 2(c) shows that funds' portfolio allocation between T-bills and the RRP is correlated with market liquidity in the T-bill market.

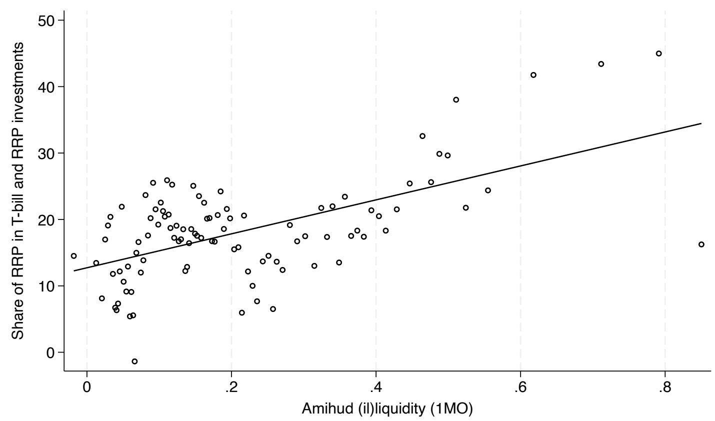
Figure 2: Concentration and MMF portfolio allocation



(a) Market shares of top 5/top 10 funds



(b) Market shares of funds in repos with banks and T-bills are positively correlated



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

Note: In Panel 2(a), we plot the average share of the largest five (Top 5) and largest 10 (Top 10) funds out of total MMF investments for each instrument, averaged over the sample period. In Panel 2(b), 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(c), 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.

When the market is less liquid (measured by the Amihud illiquidity index, for which higher values indicate lower liquidity), funds' portfolios are tilted towards the RRP relative to T-bills.

Building on these stylized facts, in the following section, we delve deeper into understanding theoretically 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.

3 Model

To illustrate the trade-offs and mechanisms we study empirically, we examine the portfolio allocation and repo pricing behavior of MMFs in a parsimonious two-period model. In the model, MMFs have an endogenous price impact in the T-bill market through their portfolio allocations. MMFs choose repo pricing and repo allocations in the first period, and allocate the remainder of their funds between T-bills and the Federal Reserve's RRP facility in the second period.[11] The model yields testable predictions for how MMFs affect the equilibrium spread between the RRP and T-bill yields, repo rates and MMF portfolio allocations.

3.1 Timeline and setup

The model has two periods. Let F be the number of MMFs. In the first period, each fund $i \in F$ is endowed with one unit of cash and chooses a gross rate r_i and lends quantity $\Delta_i^{repo} \in [0, 1]$ to banks in the repo market. Banks have a downward-sloping demand for repos. In the second period, the remaining cash ($\Delta_i = 1 - \Delta_i^{repo}$), which we refer to as "residual cash share" throughout the paper, is allocated between T-bills and the RRP. T-bill yields are endogenously determined in equilibrium. We first solve the second period problem, taking Δ_i as given, and then return to the first period problem in Section 3.4.

[11] This sequencing reflects institutional features of the U.S. money markets and the operational behavior of MMFs. Private repos in the tri-party market typically settle early in the morning. In contrast, the RRP facility settles later in the afternoon. The facility is explicitly designed as a backstop, providing a floor on short-term rates and absorbing residual liquidity that MMFs are unable to deploy more profitably in private markets.

3.2 Second period equilibrium

In period 2 each fund i chooses which share $x_i \in [0,1]$ of its residual cash Δ_i to allocate to T-bills. The remaining $(1-x_i)\Delta_i$ is invested in the RRP. T-bill prices respond to total MMF demand via linear price impact. Assume fund i's price impact is given by coefficient λ_i. Then, the aggregate T-bill yield ρ^T is given by:

$$\rho^T = \bar{\rho} - \sum_{i=1}^{F} \lambda_i x_i \Delta_i,$$

where $\bar{\rho}$ denotes the T-bill rate in the absence of MMF price impact. The RRP rate ρ^s is an administered rate by the Federal Reserve and is fixed. To mirror the interior solution for T-bill and RRP shares that we observe in the data, we assume that funds face a quadratic cost of investing in the RRP facility.

The return of fund i in the second period is hence:

$$U_i = x_i \Delta_i \rho^T + (1-x_i)\Delta_i \rho^s - \kappa((1-x_i)\Delta_i)^2, \tag{1}$$

where $\kappa > 0$ captures the cost of using the RRP.

To keep the model simple, we assume all funds are symmetric: $\lambda_i = \lambda$ and $\Delta_i = \Delta$. In this case, a higher λ reflects lower liquidity in the T-bill market.

The first–order condition is

$$(\rho^T - \rho^s) \; + \; x_i \frac{\partial \rho^T}{\partial x_i} \; + \; 2\,\kappa\,\Delta\,(1-x_i) = 0,$$

where $\frac{\partial \rho^T}{\partial x_i} = -\,\lambda\,\Delta$.

Solving each fund's optimization problem yields a unique symmetric equilibrium. Since, in equilibrium, $x_i = x^*$ for all i, the T-bill yield simplifies to:

$$\rho^T = \bar{\rho} - \lambda F x^* \Delta.$$

The unique equilibrium is given by the following, where, for simplicity, we define $A := \bar{\rho} - \rho^s > 0$:[12]

$$x^* = \frac{A + 2\kappa\Delta}{\Delta(\lambda(F+1) + 2\kappa)}. \tag{2}$$

Since $A > 0$ and $\kappa > 0$, $x^* > 0$. To ensure that $x^* < 1$, we assume that $A < \Delta(\lambda(F+1))$.

The equilibrium RRP–T-bill spread is:

$$\text{RRP–T–bill spread*} = -A\left[1 - \frac{\lambda F}{\lambda(F+1) + 2\,\kappa}\right] + \frac{2\,\kappa\,\lambda F\,\Delta}{\lambda(F+1) + 2\,\kappa}. \tag{3}$$

The following propositions with comparative statics follow directly from equations (2) and (3).

Proposition 3.1 Aggregate MMF price impact in the T-bill market*:*

- *A higher MMF residual cash share (Δ) leads to a larger RRP–T-bill spread.*
- *MMFs' price impact in the T-bill market is greater during times of low T-bill liquidity (when λ is high).*

Proposition 3.2 Tbill vs RRP share in MMF portfolios*:*

- *The share of T-bills (x) in funds' portfolios is decreasing in the residual cash share (Δ).*
- *When the T-bill market is less liquid (high λ), a higher share of residual cash is allocated to the RRP.*

3.3 The role of concentration when total residual cash is fixed

In Section 2, we documented significant concentration in the MMF sector. To illustrate the effects of concentration, we fix the total residual cash in the MMF sector but vary its concentration across F funds to generate comparative statics with respect to the number of funds.

[12] The frictionless return on T-bills is denoted by $\bar{\rho}$. A positive A is consistent with the RRP facility being safer and more liquid than T-bills absent frictions in the MMF sector.

Let total residual cash be denoted by

$$\delta := F\,\Delta,$$

where Δ is the per–fund residual cash available for the second–period allocation between T–bills and the RRP.

Holding total cash fixed. With symmetry $x_i = x$ and $A := \bar{\rho} - \rho^s$, and since $\frac{\partial \rho^T}{\partial x} = -\,\lambda\,\Delta$, x^* is still given by equation (2). Aggregate T–bill demand is $Q = F\,\Delta\,x^*$, and the RRP–T–bill spread is

$$\text{RRP–T–bill spread}(F, \Delta) = -A + \lambda Q = \frac{-A(\lambda + 2\kappa) + 2\,\lambda\,\kappa\,F\,\Delta}{\lambda(F+1) + 2\,\kappa}.$$

Substituting $\Delta = \delta/F$ to write the spread as a function of (F, δ), we obtain:

$$\text{RRP–T–bill spread}(F; \delta) = \frac{-A(\lambda + 2\kappa) + 2\,\lambda\,\kappa\,\delta}{\lambda(F+1) + 2\,\kappa}.$$

The marginal effect of an incremental cash inflow from the MMF sector into the T-bill market on the spread is:

$$\frac{\partial\,\text{Spread}}{\partial \delta} = \frac{2\,\lambda\,\kappa}{\lambda(F+1) + 2\,\kappa},$$

which is strictly decreasing in F.

We formalize this result in the following proposition.

Proposition 3.3 Concentrated T-bill purchases have a larger price impact:

When funds are homogeneous and $\Delta = \delta/F$, so that total MMF residual cash is δ, then the equilibrium impact of δ on the RRP-Tbill spread is monotonically decreasing in F.

Splitting a fixed total MMF residual cash, δ, across many identical MMFs makes each fund's order smaller. Because each fund internalizes only *its own* price impact, while the convex cash cost makes moving out of the RRP facility valuable, the optimal T-bill share, x, reflects a trade-off between worsening T-bill pricing and avoiding costs of investing in the RRP facility. When $\Delta = \delta/F$ falls, funds' own price impact shrinks and each fund's demand becomes *more elastic*. Aggregating across funds F, such more elastic demands yields a flatter market demand curve for T-bills, so the T-bill yield needs to move less to absorb extra MMF demand.

3.4 First-period repo decision

In the first period, each MMF i has one unit of funds to invest across three asset classes in two periods. Investing in repo, denoted as Δ_i^{repo}, earns a gross return r_i. Assume a reduced form downward-sloping demand for repos by banks given by $C \cdot {r_i}^{-\xi}$, with $\xi > 1$. In the second period, residual cash $\Delta_i = 1 - \Delta_i^{\text{repo}}$ is allocated between T-bills and the RRP facility. The fund obtains an endogenous return $\hat{\rho}(\Delta_i)$.

MMF i chooses r_i to maximize total return:

$$\max_{r_i} \left\{ \hat{\rho}\big(1 - \Delta_i^{repo}\big) + \Delta_i^{repo} \cdot \big(r_i - \hat{\rho}\big(1 - \Delta_i^{repo}\big)\big) \right\},$$

subject to $\Delta_i^{repo} = C \cdot {r_i}^{-\xi}$.

This leads to the optimal repo rate:

$$r_i^\star(\Delta_i) = \frac{\xi}{\xi - 1}\left[\hat{\rho}(\Delta_i) + \Delta_i \cdot \hat{\rho}'(\Delta_i)\right] = \frac{\xi}{\xi - 1}\frac{dU_i(x_i^*, \Delta_i)}{d\Delta_i},$$

where the function $U_i(x_i^*, \Delta_i)$ is the second period total return evaluated at the optimal x_i^* and is given by equation (1). Plugging in the optimal value for the T-bill share given by equation (2) and using the envelope theorem and assuming, for simplicity, that funds are homogenous (see Appendix B.1 for details), yields:

$$\frac{dU(x^*, \Delta)}{d\Delta} = \rho^s + \frac{2\kappa}{\lambda(F+1) + 2\kappa}\big(A - \lambda(F+1)\Delta\big).$$

With homogenous funds, the repo rate (as an implicit function) can be expressed as:

$$r^\star(\Delta) = \frac{\xi}{\xi - 1}\left[\rho^s + \frac{2\kappa}{\lambda(F+1)+2\kappa}\Big(A - \lambda(F+1)\Delta(r^*)\Big)\right], \tag{4}$$

where $\Delta(r) = 1 - C(r^{-\xi})$.

The following proposition directly follows from equation (4) (see Appendix B.2 for the proof):

Proposition 3.4 Repo rates and cross-market price impact internalization*:*

When MMFs internalize their price impact across markets,

- *the repo rate decreases in banks' demand elasticity for repos (or the repo rate increases as banks' demand becomes less elastic),* $\frac{\partial r^*}{\partial \xi} < 0$*;*
- *the repo rate is lower when the T-bill price impact is larger,* $\frac{\partial r^*}{\partial \lambda} < 0$.

3.5 Summary and testable predictions

We map the model's theoretical results to the following empirical predictions.

Prediction 1. By Proposition 3.1, the equilibrium T-bill rate depends negatively on funds' residual cash share, in particular when liquidity in the T-bill market is low.

While this prediction is related to the aggregate price impact of the MMF sector, this result could be driven by general equilibrium effects with many small funds. To illustrate how concentration in the MMF sector affects T-bill price impact, we test the following prediction:

Prediction 2. By Proposition 3.3, the aggregate price impact of MMFs' on the T-bill market is greater if the purchases are concentrated among fewer funds.

Apart from the importance of concentration, another key insight of our model is that strategic MMFs mark down repo rates that they offer to banks and their portfolio allocations across assets to internalize their own price impact in the T-bill market.

In the repo market, MMFs face the following trade-off. If they charge a high repo rate, they bring a higher residual cash to the second period T-bill and the RRP market and receive a lower return in the second period. All else constant, if bank demand for repos is more less elastic, MMFs can alleviate this concern by charging a higher repo rate. On the other hand, if their price impact in the T-bill market is stronger, they charge a lower repo rate.

Prediction 3. By Proposition 3.4, repo rates decrease when funds' price impact in the T-bill market is higher. Conversely, repo rates increase with higher MMF pricing power (i.e., less elastic demand by banks).

Empirically, we test **Prediction 3** using both variation in the cross-section and over time. We use proxies and contrast funds with higher vs lower price impact in the T-bill market as well as higher vs lower pricing power in the repo markets. Moreover, we also test how liquidity conditions in the T-bill market affect the repo rates.

Finally, the model yields the following prediction for the allocation between T-bills and the RRP facility, which we also test using cross-sectional variation across funds:

Prediction 4. By Proposition 3.2, funds with a higher residual cash share increase the share of the RRP in their portfolios. Funds also favor the RRP facility when the T-bill market is less liquid.

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

In this section, we test **Predictions 1 & 2** on the aggregate impact of MMFs on T-bill rates. To tackle identification challenges arising from possible endogeneity of funds' residual cash share and establish causality, we construct instrumental variables.

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 effective federal funds rate, and the VIX from FRED. We also collect data on publicly held T-bills outstanding from the US Treasury and GDP from FRED (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.[13] We compute the RRP-Tbill spread as the realized rate on the overnight RRP facility compounded over a month minus the 1-month T-bill rate in month t.[14]

Our key independent variable, $residual\ cash\ share_t$, is constructed using portfolio-holding level data from the monthly regulatory filings of MMFs to the SEC.[15] It 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:

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

We construct an instrumental variable for the residual cash share, which we discuss in further detail below. The instrument $\%\Delta$ *Euro repo* is constructed as the percentage change in the volume of repo transactions between US MMFs 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.

Table 1 presents the summary statistics of our main variables over the 143 months in our sample period (2011m2 to 2022m12). We end our sample period at the end of 2022 since, starting

[13]In the literature, this measure is typically used with daily or intraday data. Due to data availability, we are only able to construct it at a weekly frequency, and hence, our measure contains some noise. We plot the time series of our measure in the Internet Appendix (Figure A4). Consistent with other measures, this measure rises during debt ceiling episodes, the March 2020 dash-for-cash episode, and during tightening cycles. The correlation between this measure and bid-ask spreads for 1-month treasuries, obtained from Bloomberg, is 41%.

[14]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. 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.

[15]We show the robustness of our results to alternative definitions in the Internet Appendix.

in 2023 there is no more quarter-end window dressing behavior. The reason is that, since the implementation of Basel III regulations, regulators have pressured European banks to switch from quarter-end reporting to quarterly averaging. The RRP-Tbill spread averages −2 bps with a sizeable standard deviation of 10.7 bps. The residual cash shares average 39%, with a median of 35%. The average change in European banks' repo holdings between the month before the quarter-end and the quarter-end is −31.5%.

Table 1: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	P50
RRP-Tbill	143	-2	10.7	-44.71	44.25	-1
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
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. The $RRP(1M)-Tbill\ (1M)$ is in basis points and 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 *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. *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.

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:

$$RRP\ (1M) - Tbill\ (1M)_t = \beta\ residual\ cash\ share_t + controls_t + \epsilon_t. \tag{5}$$

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. We lag the 1-month realized

RRP rate by one month to cover the same time period as the 1-month T-bill rate.[16] 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 standard errors that are robust to heteroskedasticity and autocorrelation. The model predicts that a higher share of residual cash from repo lending has a positive effect on the RRP-Tbill spread, so $\beta > 0$.

The model further predicts that the effect of the residual cash share on the RRP-Tbill spread is stronger when the Treasury market is less liquid. To test this prediction we split the sample into periods of high and low T-bill liquidity based on the Amihud (2002) illiquidity measure.

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, the coefficient of interest in equations (5) cannot be interpreted as causal directly.

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.[17] During our sample period, European banks were allowed to report their Basel III leverage ratio based on a quarter-end snapshot of their balance sheet, as opposed to a measure based on the daily averages over the entire quarter. This allowed them to expand balance sheets outside of quarter-end dates without regulatory restrictions, resulting in "zigzags" in the time series of total repo borrowing, as shown in Figure 3(a).[18] European banks have used this extra balance sheet capacity to act as repo intermediaries, borrowing money from MMFs and lending it on to other counterparties, such as hedge funds with US Treasury collateral. Repo intermediation is

[16] 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.

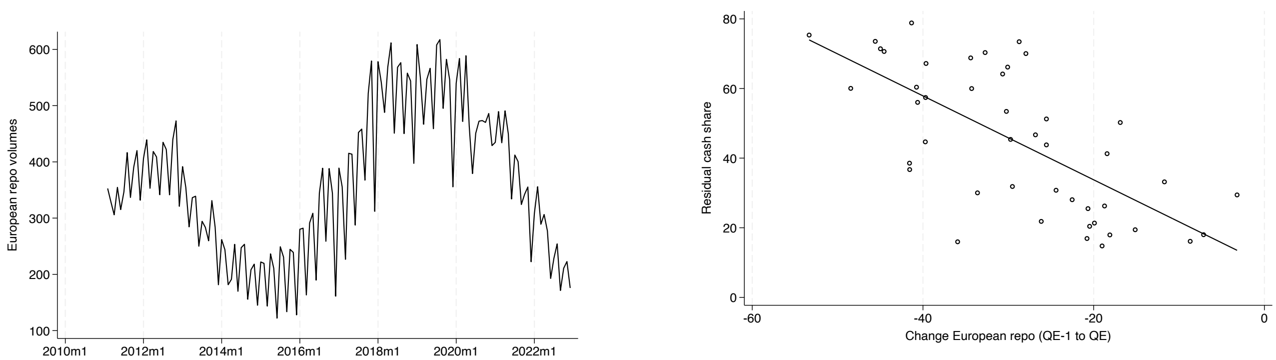
[17] We include all banks headquartered in the Euro area plus banks in the United Kingdom and Switzerland as they also withdraw from the repo market at the quarter-end in a similar manner. In the Internet Appendix, we also plot the repo volumes between MMFs and the rest of the banks in the sample. Their repo borrowing is smoother, and they step in at quarter-ends to borrow from MMFs to take advantage of the quarter-end withdrawal of other counterparties. However, as our first stage results show, the quarter-end withdrawal results in a negative repo demand shock overall.

[18] 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.

balance sheet intensive but easy to scale back. Therefore, at quarter-ends, these banks sharply reduced the balance sheet intensive repo intermediation in order to lower their leverage and comply with regulations (Aldasoro et al., 2022). The banks typically return to repo markets shortly after the quarter end (Munyan, 2017).

The negative demand shock for repos by European banks affects investment opportunities available to MMFs. Being unable to place their funds with European banks, MMFs have higher residual cash following the lower repo demand by European banks. As shown in Figure 3(b), European banks' quarter-end change in repo transactions with MMFs has a strong negative correlation with funds' residual cash share.

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



(a) European banks' demand for repos

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

Notes: Panel (a) plots the time series of European banks' repo activity with US MMF in billion dollars. 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. It is computed as the aggregate investments in T-bills and the RRP facility as a share of aggregate investments in T-bills, the RRP facility and reverse repos with banks as described in the text. Source: Crane Data.

The exclusion restriction requires that the lower repo demand by European banks is unrelated to MMFs' portfolio decisions and developments in the T-bill market. In our setting, the quarter-end retrenchment by European banks is driven by how their global business has expanded during the whole quarter and how much their balance sheets need to shrink to comply with regulations. The retrenchment is hence unlikely a function of the prevailing conditions in the repo or T-bill market in the United States nor of MMFs' behavior.

The exclusion restriction could be violated, however, if European banks increase their demand for T-bills while reducing their demand for repos with US MMFs. Then, any observed decline in the T-bill rate would occur not only because of a change in MMFs' residual cash share but also because of higher demand by European banks. A number of facts speak against this concern. First, the aim of European banks at quarter-ends is to reduce their balance sheet size. They do so by reducing their repo borrowing and lending. Purchasing T-bills would not align with this goal. Second, as we show in Figure A1(a) in the Appendix, 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.[19] This can also be seen in column (1) of Table 2, which regresses our instrument, $\%\Delta \textit{Euro repo}$, the percent change in the European repo borrowing between the month before a quarter-end and the quarter-end, on the percent change in the T-bill holdings of foreign banks. The estimated coefficient is insignificant, and the R^2 is very close to 0.

Another threat to the validity of the instrument is if any repo counterparty of European banks buys T-bills as European banks retreat from the repo markets. Again, this is not likely since counterparties are predominately cash borrowers. When European banks stop lending, they do not have the cash available to purchase T-bills. Consistent with this argument, we show that overnight repo volumes in the cleared segments of the repo market increase at quarter-ends, suggesting that these counterparties temporarily replace lost repo fundings by forming short-term relationships with other counterparties in other segments of the repo market. The most likely counterparties are primary dealers whose T-bill holdings at quarter-ends are uncorrelated with $\%\Delta \textit{Euro repo}$ (see Table 2, column (2)). We also show that the T-bill holdings of hedge funds and commercial banks exhibit no abrupt changes at quarter-ends (see Table 2, column (3)–(4)).[20] Also consistent with

[19] While no breakdown of T-bill 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 in the market, significant changes in their demand for T-bills are likely to affect the holdings of T-bills by foreign banks on aggregate.

[20] We construct the changes analogous to $\%\Delta \textit{Euro repo}$ foreign banks and primary dealers, since we have monthly data. For hedge funds and commercial banks, we only have quarterly data. Hence, we take quarterly changes.

Table 2: Evidence in favor of the exclusion restriction: $\%\Delta Euro\ repo$ is not correlated with various potential confounders

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
% Ch. Foreign bank T-bill holdings (quarter-end)	-0.08					
	(0.37)					
% Ch. Primary Dealer T-bill holdings (quarter-end)		-0.03				
		(0.06)				
% Ch. Hedge Fund UST holdings (quarter-end)			0.11			
			(0.27)			
% Ch. Comm. Bank UST and Agency holdings (quarter-end)				2.33		
				(1.87)		
SP500 return					-0.04	
					(0.46)	
Ch. 10Y ZC yield (quarter-end)						-6.02
						(8.52)
Observations	48	48	40	48	48	48
R-squared	0.00	0.01	0.00	0.02	0.00	0.01

Notes: The dependent variable in all columns is the $\%\Delta$ *Euro repo*. Similar to its construction, all independent variables are constructed as the percent change between the month before the quarter-end and the quarter-end, except hedge funds and commercial banks. For these sectors, we only have quarterly data available, hence we take per cent change in the quarterly data. Standard errors are robust to heteroskedasticity and autocorrelation using a Bartlett kernel with a bandwidth of 6. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Bloomberg, Crane Data, Federal Reserve Bank of New York, FRED, SEC Form PF, US Treasury.

the satisfaction of the exclusion restriction, Correa et al. (2020) show that US GSIBs increase their dollar liquidity provision in response to dollar funding shortages at quarter-ends, which is mainly financed by reducing excess reserves at the Federal Reserve.[21] Therefore, their T-bill holdings are not affected.

A third possibility for the exclusion restriction to be violated is if European banks do not respond to regulatory incentives but instead respond to economic conditions in the US economy. To rule out this possibility, we show that the European repo shock variable has no significant correlation with the contemporaneous returns on the S&P 500 and the 10-year Treasury yield (see Table 2, columns (5)–(6)).[22]

All in all, the evidence above is consistent with the satisfaction of the exclusion restriction

[21]See also Wallen (2020) for the US banks filling the gap in the synthetic dollar funding market at quarter-ends.
[22]We report all scatterplots of these variables in Appendix A.1.

and suggests that the negative repo demand shock affects T-bill rates only through its effect on investment opportunities of MMFs, i.e., their residual cash. It appears unlikely that changes in quarter-end repo demand by European banks are driven by prevailing conditions in the US T-bill or repo market.

Table 3 presents the results of OLS and 2SLS regressions on our main regression specification (see equation (5)). In column (1), we regress the RRP-Tbill spread on variables that are commonly used in the literature to explain spreads: the federal funds rate, log(bills to GDP), and the VIX. We find a significant coefficient on the T-bill supply consistent with the results in d'Avernas and Vandeweyer (2023).[23]

In column (2), we include *residual cash share* as an additional regressor. As predicted by our model, the coefficient is positive. It is statistically significant at the 1% level. Interestingly, the R^2 jumps from 2% to 41% when we include the *residual cash share*.

To estimate the causal effect of the *residual cash share* on the RRP-Tbill spread, column (3) 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.[24] The effective F statistic (as computed in Olea and Pflueger (2013)) equals 29.71. When we compute the weak-instrument robust 90% confidence set for our estimates using the Anderson-Rubin procedure, as recommended by Andrews et al. (2019), the interval safely excludes zero. The 2SLS estimates are close in magnitude to their OLS counterpart in column (2).[25]

In terms of magnitude, 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 a 0.5% decrease in the bills-to-GDP ratio. Hence,

[23] 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.

[24] Table A1 in the Appendix provides the first stage regressions.

[25] 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.

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

VARIABLES	(1) OLS RRP-Tbill	(2) OLS RRP-Tbill	(3) 2SLS RRP-Tbill	(4) High Tbill liquidity 2SLS RRP-Tbill	(5) Low Tbill liquidity 2SLS RRP-Tbill	(6) Low Tbill HHI 2SLS RRP-Tbill	(7) High Tbill HHI 2SLS RRP-Tbill
residual cash share		0.37***	0.32***	0.19***	0.56***	0.18***	0.44**
		(0.08)	(0.10)	(0.06)	(0.16)	(0.03)	(0.19)
FFR	0.11	-1.32	2.39	-3.93*	-2.53	2.41	1.86
	(3.08)	(1.83)	(3.15)	(2.15)	(4.50)	(1.60)	(3.66)
log(bills to GDP)	-5.99*	-19.29***	-12.57***	-14.29***	41.86	-8.92***	-17.64*
	(3.27)	(3.80)	(4.46)	(3.06)	(27.37)	(2.31)	(9.22)
VIX	0.09	0.01	-0.12	0.10	-0.66***	0.04	-0.13
	(0.34)	(0.29)	(0.36)	(0.12)	(0.21)	(0.22)	(0.41)
Observations	143	143	48	25	23	22	26
R-squared	0.02	0.41					
Effective F-stat			29.71	14.40	15.01	7.92	16.22
Anderson-Rubin test (p-val)			0.01	0.02	0.04	0.02	0.06
AR 90% CI (lower)			0.16	0.08	0.24	0.10	0.09
AR 90% CI (upper)			0.51	0.36	0.94	0.24	0.89

Note: This table reports results for equation (5). 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 regressions. Columns (3) to (7) report the second stage of 2SLS regressions, in which %Δ *Euro repo* instruments *residual cash share*. The sample is thus restricted to quarter-ends. In columns (4) and (5), we restrict the sample to periods with above median and below median liquidity in the T-bill market, respectively, based on an Amihud illiquidity measure. Columns (6) and (7) split the sample into periods of low and high concentration in MMF purchases in the Tbill market. In 2SLS regressions, we report the p-value of the Anderson-Rubin test and the effective F statistic as in Olea and Pflueger (2013). Columns (3) to (7) report weak-instrument robust 90% confidence intervals for our estimates, which are obtained by inverting the Anderson-Rubin test (see Andrews et al., 2019). Standard errors are robust to heteroskedasticity and autocorrelation using a Bartlett kernel with a bandwidth of 6. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data, FRED, US Treasury.

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

Columns (4) and (5) investigate whether the effect of the residual cash share on the spread is stronger during times of illiquidity in the Tbill market.[26] Consistent with the model's prediction the impact of the residual cash share on the RRP-Tbill spread is substantially larger when T-bill market is less liquid (in column (4) vs column (5)).

In sum, columns (2)–(5) of Table 3 provide support for **Prediction 1**: A higher aggregate

[26]We construct an Amihud illiquidity measure and plot it in the Appendix. Our results remain similar if we instead use bid-ask spreads on 1-month T-bills (see Table A3).

MMF residual cash share increases the RRP-Tbill spread, especially when the Treasury market is illiquid.

4.3 The impact of concentrated T-bill purchases on T-bill rates

We now test **Prediction 2**, which suggests that concentrated T-bill purchases have a larger impact on T-bill rates, which allows us to study the impact of MMF sector concentration on T-bill rates and the RRP-Tbill spread.

We split the sample into two sub-samples: one with months with a lower concentration of MMF purchases of T-bills and the other with a higher concentration. We measure concentration with an HHI index based on the concentration of MMF purchases in the T-bill market and split the sample into the top and bottom half of the HHI distribution. In line with our predictions, we find that in 2SLS regressions, the aggregate price impact of MMFs is substantially larger when their purchases are concentrated (Table 3, column (7)) compared to when they are not (column (6)).

4.4 MMF price impact in the T-bill market at a higher frequency

An important feature of the European withdrawal from US repo markets is that, since it is a response to regulatory incentives around quarter-ends, European banks' repo demand rebounds quickly at the beginning of the next quarter (Munyan, 2017). To further strengthen the identification and address potential issues that might arise in monthly data with 1-month T-bill rates, we focus on daily data and study the pricing of very short term T-bills with a remaining maturity of a few days. The impact of the substitution by MMFs from lending to European banks into purchasing T-bills should be the most prevalent for these very short-term T-bills since they would act to bridge the quarter-end. Since the Treasury generally conducts weekly auctions, we follow T-bills on their last few days before expiration. Every week, we follow a different T-bill, hence the days to maturity around quarter-ends vary, but it is never longer than five days. As a result, we can trace the pricing of these very short-term T-bills around quarter-ends and outside quarter-end periods.

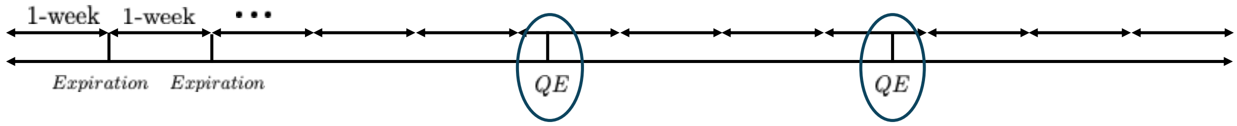


Figure 4: Daily regressions of MMF price impact on T-bill rates

Specifically, we use the European bank withdrawal as a direct shock and focus on a 2-day window around quarter-ends. We run the following daily regression:

$$Tbill\ rate_t = \gamma\ \mathbb{1}(2\ Days\ Around\ QE_t) \times \%\Delta European\ repo\ (closest\ QE)_t$$
$$+ controls_t + Week\ FE + \varepsilon_t\ ,$$

where we regress the daily T-bill rate on the interaction of a dummy, which is one if the date is the quarter-end itself or two days around it, and the European bank repo withdrawal during that quarter-end (compared to the month before). We control for the same set of controls as in the previous regression, as well as the days to maturity of the T-bill. To account for broader macro factors, we also include week-fixed effects. To be consistent with our model, the coefficient in this regression should be positive: when European banks retreat by more (the independent variable becomes more negative), T-bill rates should fall by more.

We indeed find that when the quarter-end withdrawal of European banks is larger, the rates on very short-term T-bills fall more on two days around quarter-ends. When we split the sample between high and low liquidity periods in the T-bill market, we find that the effect is larger during low T-bill liquidity periods. Finally, we split the sample again into periods of high T-bill purchase concentration and low T-bill purchase concentration by MMFs. We get similar results as in the monthly data: the price impact is larger during periods of highly concentrated purchases. We report the detailed results in Table A2.

4.5 Additional results and robustness checks

Additional suggestive evidence on individual impact. To provide further evidence on the individual price impact of MMFs, we focus on European repo demand shocks at the individual fund family level. In particular, we regress the RRP-Tbill spread on individual fund family residual cash share and other controls. We use two instruments for the individual fund family residual cash share: the aggregate European repo demand shock and the European repo demand shock at the fund family level. We find that the coefficient estimates for the impact of individual residual cash share on the RRP-Tbill spread tend to be greater for larger fund families. We take this as alternative suggestive evidence for the individual price impact of MMFs in the T-bill market. We show our family-by-family coefficient estimates from OLS and IV regressions in Figure A5 in the Appendix.

Alternative definitions of main dependent and independent variables. Table A3 replicates the main results using 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. In addition, it also uses the expected, rather than the realized RRP-Tbill spread, as the dependent variable using the 1-month OIS rate to gauge expectations about monetary policy. Since the correlation between expected and realized spread is very high, results remain nearly identical. Finally, our results are robust to using the bid-ask spread as an alternative liquidity indicators.[27]

5 Are MMFs acting strategically across markets? Evidence from granular data

In this section, we test **Predictions 3 & 4** regarding repo pricing and the allocations between T-bills and the RRP facility in the cross-section of funds. We test these predictions using granular contract-level data.

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

5.1 Internalizing T-bill price impact in the repo market

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.[28] 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.

According to our theory, the key objects are funds' ability to charge markups based on banks' demand elasticity as well as funds' price impact in the T-bill market. To proxy for these, we define the following two measures:

$$F\ MS\ bank\ repo_{f,t} = \frac{\sum_b bank\ repo_{f,b,t}}{\sum_f \sum_b bank\ repo_{f,b,t}} \times 100, \tag{6}$$

$$F\ MS\ Tbill_{f,t} = \frac{amount\ treasury_{f,t}}{\sum_f amount\ treasury_{f,t}} \times 100, \tag{7}$$

where f denotes fund, b bank, and t the month, and 'F MS' stands for fund market share. Higher values of $F\ MS\ bank\ repo$ proxy a greater ability of a fund to set rates in the bank repo market. $F\ MS\ Tbill$ proxies a fund's price impact in the T-bill market. We compute analogous measures at the fund family level, denoted as $FF\ MS\ bank\ repo$ ($FF\ MS\ Tbill$) to allow for the possibility that fund decisions are taken at the family level. We also construct an alternative measure of funds' (fund families') ability to set rates vis-a-vis a bank in the repo market, denoted by $F\ bargaining\ power\ repo$ and $FF\ bargaining\ power\ repo$:

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

[28] We manually clean the dataset to fix typos and inconsistencies in order to obtain consistent fund and holding variables. We also track the holdings longer than a month to reduce the sample only to new holdings in a month.

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

These measures capture the idea that if a bank relies heavily on a given fund (or fund family) for its repo borrowing, then the fund (or family) can be expected to have a higher bargaining power vis-a-vis the bank. Table 4, panel (a) provides summary statistics. The average fund (fund family) has a market share in the repo market with banks of 1.84% (11.05%), and a market share in the T-bill market of 0.8% (7.55%).

To analyze the effects of funds' market shares in the repo market with banks and the T-bill market on repo rates, we estimate variants of the following regression:

$$rate_{i(f,b),t} = \beta_1\ F\ MS\ Tbill_{f,t} + \beta_2\ F\ MS\ bank\ repo_{f,t} + controls_{i,t} + \theta + \varepsilon_{i,t}. \qquad (8)$$

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 $F\ MS\ Tbill_{f,t}$ and $F\ MS\ bank\ repo_{f,t}$ denote fund f's market share in the T-bill and bank repo markets in month t (as defined in equations (6) and (7)). Each regression controls for the size and the maturity of the contract, while θ denotes different fixed effects, which we explain in more detail below. Standard errors are double clustered at the fund and time (month) level.

According to **Prediction 3**, all else constant, the repo rate co-moves positively with a fund's pricing power. At the same time, a higher T-bill price impact (proxied by the market share in the T-bill market) should lower repo rates charged by the same fund due to the internalization of its price impact, and this effect is predicted to be stronger during times of illiquidity in the T-bill market. We hence expect $\beta_1 < 0$ and $\beta_2 > 0$.

Regression equation (8) 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 MMF pricing power. Moreover,

Table 4: Summary statistics

Panel (a): Summary statistics for variables in Table 5 (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 Tbill	278110	.8	1.14	0	15.72	.3
FF MS bank repo	278110	11.05	8.8	0	28.4	8.31
FF MS Tbill	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 6 (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 5. 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. 6). *F MS Tbill* (*FF MS Tbill*) is the market share of the fund (fund family) in the T-bill market (see Eq. 7). *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 other than the rate are in percentage points. In the lower panel, we report the summary statistics of the variables used in Table 6 at the fund-time level. The sample period for the lower panel runs between October 2013 and June 2023 (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.

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 share on repo rates when banks' market power is held constant. Finally, we will control for fund size to address the concern that our market share variables simply reflect fund size.

Table 5 shows that funds with a higher market share in the T-bill market charge lower repo rates, while, all else constant, funds with a higher market share in the repo market charge higher repo rates. Column (1) reports a negative coefficient on *F MS Tbill* ($\beta_1 < 0$) and a positive coefficient on *F MS bank repo* ($\beta_2 > 0$), both significant at the 1% level. We also interact *F MS Tbill* 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. The negative coefficient on the interaction term, significant at the 5% level, supports the model prediction. Column (2) corroborates this finding when we use market shares at the fund family level.[29]

Columns (3) and (4) replicate columns (1) and (2) but use *F bargaining power repo* and *FF bargaining power repo* instead of funds' or fund families' market share in the repo market, i.e., measures that proxy for funds' or fund families' bargaining power vis-a-vis individual banks. Results are again consistent with our predictions. Finally, columns (5) and (6) confirm these findings when we include fund family×bank fixed effects to further account for relationships between a fund family and a bank. These fixed effects absorb any unobservable variation that is fund-bank or fund-family-bank specific, including, e.g., relationship length or soft information. All in all, results in Table 5, are consistent with **Prediction 3**.[30]

[29] As we show in the Internet Appendix, controlling for size through the log of total fund holdings of repos with banks and T-bills does not materially affect our results (see Appendix Table A4).

[30] In a related paper, Huber (2023) focuses on a subset of repo contracts with overnight maturity and collateralized by US Treasuries up until December 2017 and finds evidence consistent with MMFs' aversion to portfolio concentration and preference for stable lending. As a result, dealers pay lower repo rates. Our results on T-bill market shares can provide a complementary explanation of why MMFs prefer stable lending partners rooted in the incentives to reduce price impact in the T-bill market. That said, our sample period is longer, and importantly the sample also includes different types of repo contracts, hence the positive coefficients on our proxies for MMF pricing power measures can be interpreted as coming from repo contracts that are not included in the sample used in Huber (2023). Consistent

Table 5: Funds' pricing power and internalization of T-bill price impact

VARIABLES	(1) rate	(2) FF rate	(3) rate	(4) FF rate	(5) rate	(6) FF rate
F MS Tbill	-0.329***		-0.141**		-0.215***	
	(0.093)		(0.071)		(0.076)	
F MS Tbill × Amihud	-0.135**		-0.130**		-0.149**	
	(0.056)		(0.056)		(0.059)	
FF MS Tbill		-0.050		-0.016		-0.087**
		(0.054)		(0.036)		(0.040)
FF MS Tbill × Amihud		-0.061***		-0.061***		-0.072***
		(0.019)		(0.019)		(0.018)
F MS bank repo	0.236***					
	(0.079)					
FF MS bank repo		0.102**				
		(0.049)				
F bargaining power (repo)			0.038**		0.002	
			(0.019)		(0.013)	
FF bargaining power (repo)				0.066***		0.025**
				(0.019)		(0.011)
Observations	275,331	382,985	275,331	382,985	275,292	382,955
R-squared	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 (8). Variable descriptions and summary statistics can be found in Table 4. 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. 6). *F MS Tbill* (*FF MS Tbill*) is the market share of the fund (fund family) in the T-bill market (see Eq. 7). *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 double clustered at the fund and time (month) level. Source: Crane Data. *** p<0.01, ** p<0.05, * p<0.1.

with this explanation, we replicate the analysis with the same sub-sample as Huber (2023) in Appendix Table A5 and indeed find results similar to Huber (2023) for this sub-sample.

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

Next, we turn to **Prediction 4**, which states that funds with a higher residual cash share allocate more assets to the RRP relative to T-bills, and that they favor the RRP when T-bill market liquidity is low. To test this prediction, we estimate regressions at the fund f-month t level:

$$\begin{aligned} RRP\ share_{f,t} = &\ \delta_1\ F\ residual\ cash\ share_{f,t} \\ &+\ \delta_2\ Illiquidity_t + controls_{f,t} + \phi_f + \varepsilon_{f,t}. \end{aligned} \tag{9}$$

The dependent variable $RRP\ share_{f,t}$ is the share of fund assets allocated to the RRP out of total holdings of T-bills and the RRP by fund f at time t. The main explanatory variable $F\ residual\ cash\ share_{f,t}$ denotes fund f's residual cash share in time t. The variable $Illiquidity_t$ are different measures of illiquidity in the T-bill market: the Amihud liquidity measure for T-bills; a dummy for debt ceiling episodes; and the bid-ask spread for 1-month T-bills.[31] The regression includes fund fixed effects and controls for the log change in fund assets under management and the market share of the fund in the T-bill market as well as its interactions with the 1-month T-bill rate and the federal funds rate. Standard errors are double clustered at the fund and time level. Based on **Prediction 4**, we expect that funds with higher residual cash share allocate a greater share of their assets to RRP ($\delta_1 > 0$), and that they favor the RRP liquidity conditions in the Treasury market are worse ($\delta_2 > 0$).

Table 6, 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) shows that this pattern is robust to the inclusion of year-month fixed effects. Columns (3)–(5) add the different measures of illiquidity in the T-bill market. Column (3) reports a positive coefficient on the Amihud index, 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 and do so also by more when the T-bill

[31] Cassidy and Mirani (2025) show that debt ceiling episodes are characterized by low liquidity and strong fluctuations in T-bill supply.

market is relatively illiquid. Columns (4) and (5) confirm this pattern when we use a dummy for debt ceiling episodes as an alternative indicator of liquidity in the T-bill market or when we use the bid-ask spread for 1-month T-bills.

Table 6: T-bill market liquidity and funds allocated to the RRP

	(1)	(2)	(3)	(4)	(5)
VARIABLES	RRP share	RRP share	RRP share	RRP share	RRP share
F residual cash share	0.748***	0.639***	0.757***	0.734***	0.686***
	(0.053)	(0.033)	(0.050)	(0.051)	(0.046)
Amihud index			4.573***		
			(1.109)		
debt ceiling				12.081***	
				(2.045)	
bid-ask spread					7.755***
					(0.955)
Observations	12,619	12,619	12,619	12,619	12,619
R-squared	0.599	0.738	0.618	0.621	0.639
fund FE	✓	✓	✓	✓	✓
controls	✓	✓	✓	✓	✓
time FE	-	✓	-	-	-

Note: This table reports the results for regression equation (9). Variable descriptions and summary statistics can be found in Table 4. 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. In column (3), *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 illiquidity, while column (5) reports results with the bid-ask spread for 1-month T-bills. Standard errors are double clustered at the fund and time level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data.

Taken together, these findings show that MMFs with a higher residual cash share tilt their portfolio towards the RRP, and also do so when liquidity in the T-bill market is low. Table 6 thus provides empirical evidence consistent with **Prediction 4**. The fact that funds allocate more assets to the RRP when the T-bill market is illiquid could rationalize the abrupt rise in the take-up of the RRP facility from almost zero to $2.5 trillion within months in 2022, as funds substituted their T-bills for the RRP facility as liquidity conditions in the T-bill markets worsened.

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 that forms part of the "convenience yield", is often measured as the difference between the prices of two securities that are equally safe but differ in 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.[32] 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). A higher GC repo-Tbill spread 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 in the T-bill market. And this price impact is stronger when T-bill markets are less liquid. Hence, to the extent that common measures of the liquidity premium implicitly assume negligible intermediation frictions and a highly liquid T-bill market, they might misattribute parts of the liquidity premium to frictions investor preferences rather than intermediation frictions and market illiquidity. In fact, our model suggests that the common measures of the convenience yield of T-bills increase when the T-bill market is less liquid. This price impact amplifies the impact of investor preferences on convenience yields.

To shed light on the effect of MMFs' price impact on the liquidity premium, in Table 7 we show that funds' residual cash share indeed has a significant impact on the liquidity premium of T-bills. We estimate equation (5) with the 1-month GC repo-Tbill spread as the dependent variable.

[32]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.

Column (1) 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 one 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 affects the liquidity premium, we 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 3), while column (5) shows that its effect on the GC-RRP spread is statistically and economically insignificant, as expected.[33]

Figure 5 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 standard 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,[34] 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

[33] Note that 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.

[34] 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.

Table 7: MMFs' residual cash share and the liquidity premium

	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	2SLS	2SLS	2SLS
VARIABLES	GC-Tbill	GC-Tbill	GC-Tbill	RRP-Tbill	GC-RRP
residual cash share		0.10*	0.30***	0.32***	-0.02
		(0.06)	(0.09)	(0.10)	(0.13)
FFR	3.32***	2.94**	6.19***	2.39	3.80
	(1.06)	(1.27)	(1.38)	(3.15)	(4.01)
log(bills to GDP)	-18.76***	-22.37***	-31.88***	-12.57***	-19.31***
	(3.59)	(4.41)	(4.94)	(4.46)	(7.23)
VIX	0.23	0.21	0.33***	-0.12	0.45
	(0.16)	(0.15)	(0.11)	(0.36)	(0.45)
Observations	143	143	48	48	48
R-squared	0.31	0.34			
Effective F-stat			29.71	29.71	29.71
Anderson-Rubin test (p-val)			0.01	0.01	0.86
AR 90% CI (lower)			0.14	0.16	-0.27
AR 90% CI (upper)			0.46	0.51	0.19

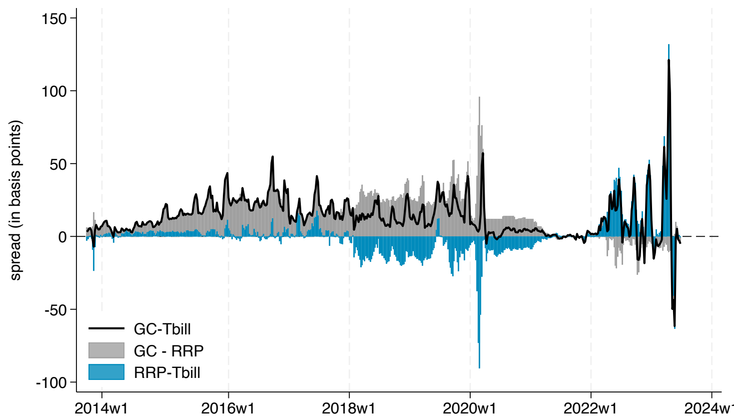
Note: This table reports results for equation (5). Variable descriptions and summary statistics can be found in Table 1. Data are at a monthly frequency between February 2011 and December 2022. Columns (1) and (2) report the results of OLS regressions. Columns (3) to (5) report the 2SLS regressions in 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). In 2SLS regressions, we report the p-value of the Anderson-Rubin test and the effective F statistic as in Olea and Pflueger (2013). Columns (3) to (5) report weak-instrument robust 90% confidence intervals for our estimates, which are obtained by inverting the Anderson-Rubin test (see Andrews et al., 2019). Standard errors are robust to heteroskedasticity and autocorrelation using a Bartlett kernel with a bandwidth of 6. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data, FRED, US Treasury.

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,[35] 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,

[35] 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.

together with illiquidity in the T-bill market, can push up the RRP-Tbill spread through funds' price impact in the T-bill market.

Figure 5: 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.

Taken together, the large movements in the RRP-Tbill spread, together with the results in Table 7 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.[36] 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 5 indicates that at times of illiquidity 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.

[36] 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.

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 in 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 et al., 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 et al., 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 et al., 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.

References

Acharya, Viral V and Toomas Laarits, "When do Treasuries Earn the Convenience Yield? A Hedging Perspective," *Working Paper*, 2023.

Adrian, Tobias, Erkko Etula, and Tyler Muir, "Financial intermediaries and the cross-section of asset returns," *The Journal of Finance*, 2014, *69* (6), 2557–2596.

Afonso, Gara, Marco Cipriani, and Gabriele La Spada, "Banks' Balance-Sheet Costs, Monetary Policy, and the ON RRP," *FRB of New York Staff Report*, 2022, (1041).

Aldasoro, Iñaki and Sebastian Doerr, "Who borrows from money market funds?," *BIS Quarterly Review*, 2023, pp. 47–59.

—— **, Torsten Ehlers, and Egemen Eren**, "Global banks, dollar funding, and regulation," *Journal of International Economics*, 2022, *137*, 103609.

Amihud, Yakov, "Illiquidity and stock returns: cross-section and time-series effects," *Journal of Financial Markets*, 2002, *5* (1), 31–56.

—— **and Haim Mendelson**, "Liquidity, maturity, and the yields on US Treasury securities," *The Journal of Finance*, 1991, *46* (4), 1411–1425.

Anderson, Alyssa, Wenxin Du, and Bernd Schlusche, "Arbitrage Capital of Global Banks," *working paper*, 2022.

Andrews, Isaiah, James H Stock, and Liyang Sun, "Weak instruments in instrumental variables regression: Theory and practice," *Annual Review of Economics*, 2019, *11* (1).

Barth, Daniel and R Jay Kahn, "Hedge funds and the Treasury cash-futures disconnect," *OFR WP*, 2021, pp. 21–01.

Basak, Suleyman and Anna Pavlova, "Asset prices and institutional investors," *American Economic Review*, 2013, *103* (5), 1728–1758.

Brunnermeier, Markus K and Yuliy Sannikov, "A macroeconomic model with a financial sector," *American Economic Review*, 2014, *104* (2), 379–421.

Cassidy, William and Shreye Mirani, "The Debt Ceiling's Disruptive Impact: Evidence from Many Markets," *Chicago Booth Research Paper*, 2025.

Chernenko, Sergey and Adi Sunderam, "Frictions in Shadow Banking: Evidence from the Lending Behavior of Money Market Mutual Funds," *Review of Financial Studies*, 2014, *27*, 1717–1750.

Cieslak, Anna, Wenhao Li, and Carolin Pflueger, "Inflation and treasury convenience," Technical Report, National Bureau of Economic Research 2024.

Cipriani, Marco and Gabriele La Spada, "Investors' appetite for money-like assets: The MMF industry after the 2014 regulatory reform," *Journal of Financial Economics*, 2021, *140* (1), 250–269.

Copeland, Adam, Antoine Martin, and Michael Walker, "Repo runs: Evidence from the tri-party repo market," *Journal of Finance*, 2014, *69* (6), 2343–2380.

Corell, Felix, Lira Mota, and Melina Papoutsi, "Learning from Holdings: Drivers of Convenience Yield and Policy Implications," *Available at SSRN 4656963*, 2023.

Correa, Ricardo, Wenxin Du, and Gordon Y Liao, "US banks and global liquidity," Technical Report, National Bureau of Economic Research 2020.

d'Avernas, Adrien and Quentin Vandeweyer, "Treasury bill shortages and the pricing of short-term assets," *The Journal of Finance*, 2023.

___ , ___ , and Damon Petersen, "The Central Bank's Balance Sheet and Treasury Market Disruptions," *Available at SSRN 4826919*, 2024.

Drechsler, Itamar, Alexi Savov, and Philipp Schnabl, "The deposits channel of monetary policy," *The Quarterly Journal of Economics*, 2017, *132* (4), 1819–1876.

Du, Wenxin, Benjamin Hébert, and Amy Wang Huber, "Are intermediary constraints priced?," *The Review of Financial Studies*, 2023, *36* (4), 1464–1507.

Duffee, Gregory R, "Idiosyncratic variation of Treasury bill yields," *The Journal of Finance*, 1996, *51* (2), 527–551.

Duffie, Darrell, "Still the World's Safe Haven?," *Redesigning the US Treasury market after the COVID-19 crisis', Hutchins Center on Fiscal and Monetary Policy at Brookings, available online at https://www. brookings. edu/research/still-the-worlds-safe-haven*, 2020.

—— **and Arvind Krishnamurthy**, "Passthrough efficiency in the Fed's new monetary policy setting," in "Designing Resilient Monetary Policy Frameworks for the Future. Federal Reserve Bank of Kansas City, Jackson Hole Symposium" 2016, pp. 1815–1847.

Eren, Egemen and Philip D Wooldridge, "Non-bank financial institutions and the functioning of government bond markets," *BIS Papers*, 2021, (119).

—— **, Andreas Schrimpf, and Vladyslav Sushko**, "US dollar funding markets during the Covid-19 crisis - the international dimension," *BIS Bulletin no.15*, 2020.

—— **,** —— **, and** —— , "US dollar funding markets during the Covid-19 crisis - the money market fund turmoil," *BIS Bulletin no.14*, 2020.

Greenwood, Robin, Samuel G Hanson, and Jeremy C Stein, "A comparative-advantage approach to government debt maturity," *The Journal of Finance*, 2015, *70* (4), 1683–1722.

Gromb, Denis and Dimitri Vayanos, "The dynamics of financially constrained arbitrage," *The Journal of Finance*, 2018, *73* (4), 1713–1750.

Han, Song and Kleopatra Nikolaou, "Trading Relationships in the OTC Market for Secured Claims: Evidence from Triparty Repos," FEDS Working Paper 2016-64, Federal Reserve Board 2016.

He, Zhiguo and Arvind Krishnamurthy, "Intermediary asset pricing," *American Economic Review*, 2013, *103* (2), 732–770.

—— **, Bryan Kelly, and Asaf Manela**, "Intermediary asset pricing: New evidence from many asset classes," *Journal of Financial Economics*, 2017, *126* (1), 1–35.

—— **, Stefan Nagel, and Zhaogang Song**, "Treasury inconvenience yields during the covid-19 crisis," *Journal of Financial Economics*, 2022, *143* (1), 57–79.

Hu, Grace Xing, Jun Pan, and Jiang Wang, "Tri-party repo pricing," *Journal of Financial and Quantitative Analysis*, 2021, *56* (1), 337–371.

Huber, Amy Wang, "Market power in wholesale funding: A structural perspective from the triparty repo market," *Journal of Financial Economics*, 2023, *149* (2), 235–259.

Infante, Sebastian, "Private money creation with safe assets and term premia," *Journal of Financial Economics*, 2020, *136* (3), 828–856.

Kacperczyk, Marcin and Philipp Schnabl, "How Safe Are Money Market Funds?," *The Quarterly Journal of Economics*, 2013, *128* (3), 1413–42.

Krishnamurthy, Arvind and Annette Vissing-Jorgensen, "The aggregate demand for treasury debt," *Journal of Political Economy*, 2012, *120* (2), 233–267.

___ **and** ___ , "The impact of Treasury supply on financial sector lending and stability," *Journal of Financial Economics*, 2015, *118* (3), 571–600.

___ **and Wenhao Li**, "The demand for money, near-money, and treasury bonds," Technical Report, National Bureau of Economic Research 2022.

___ **, Stefan Nagel, and Dmitry Orlov**, "Sizing up repo," *Journal of Finance*, 2014, *69* (6), 2381–2417.

Lenel, Moritz, Monika Piazzesi, and Martin Schneider, "The short rate disconnect in a monetary economy," *Journal of Monetary Economics*, 2019, *106*, 59–77.

Li, Jian, Zhiyu Fu, and Yinxi Xie, "Convenience yield, inflation expectations, and public debt growth," *Inflation Expectations, and Public Debt Growth (February 5, 2022)*, 2022.

Li, Yi, "Reciprocal lending relationships in shadow banking," *Journal of Financial Economics*, 2021, *141* (2), 600–619.

Longstaff, Francis A, "The flight-to-liquidity premium in US Treasury bond prices," 2004.

Martin, Antoine, James McAndrews, Ali Palida, and David R Skeie, "Federal reserve tools for managing rates and reserves," *Available at SSRN 2335506*, 2019.

Munyan, Benjamin, "Regulatory arbitrage in repo markets," *Office of Financial Research Working Paper*, 2017, (15-22).

Nagel, Stefan, "The liquidity premium of near-money assets," *The Quarterly Journal of Economics*, 2016, *131* (4), 1927–1971.

Olea, José Luis Montiel and Carolin Pflueger, "A robust test for weak instruments," *Journal of Business & Economic Statistics*, 2013, *31* (3), 358–369.

Schmidt, Lawrence, Allan Timmermann, and Russ Wermers, "Runs on Money Market Mutual Funds," *American Economic Review*, September 2016, *106* (9), 2625–57.

Schrimpf, Andreas, Hyun Song Shin, and Vladyslav Sushko, "Leverage and margin spirals in fixed income markets during the Covid-19 crisis," *Working Paper*, 2020.

Siriwardane, Emil, Adi Sunderam, and Jonathan L Wallen, "Segmented arbitrage," Technical Report, National Bureau of Economic Research 2022.

Stein, Jeremy C and Jonathan Wallen, "The Imperfect Intermediation of Money-Like Assets," *The Journal of Finance*, 2025.

Sunderam, Adi, "Money creation and the shadow banking system," *The Review of Financial Studies*, 2015, *28* (4), 939–977.

Tella, Sebastian Di, Benjamin M Hébert, Pablo Kurlat, and Qitong Wang, "The Zero-Beta Interest Rate," Technical Report, National Bureau of Economic Research 2023.

Vissing-Jorgensen, Annette, "The treasury market in spring 2020 and the response of the federal reserve," *Journal of Monetary Economics*, 2021, *124*, 19–47.

Wallen, Jonathan, *Markups to financial intermediation in foreign exchange markets*, Stanford University, 2020.

Weil, Philippe, "The equity premium puzzle and the risk-free rate puzzle," *Journal of monetary economics*, 1989, *24* (3), 401–421.

Xiao, Kairong, "Monetary transmission through shadow banks," *The Review of Financial Studies*, 2020, *33* (6), 2379–2420.

A Internet 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' and primary dealers' holdings of short-term treasuries, hedge funds' holdings of treasuries and commercial banks' holdings of treasury and agency securities[37]. The figure also shows no correlation between the quarter-to-quarter change in European banks' repo activity with US MMF and the return on the S&P 500 and the change in the 10-year zero coupon yield. These zero correlations are in line with the exclusion restriction being satisfied, supporting the validity of our instrument.

- Figure A2: This figure plots the time series of the overnight repo volumes at the delivery-versus-payment segment of the repo market, which could be a venue the counterparties of European banks could use to replace lost repo funding. Its take-up indeed features spikes at quarter-ends. See also Correa et al. (2020) for evidence that US GSIBs increase their repo lending during quarter-ends while drawing down their excess reserves at the Federal Reserve.

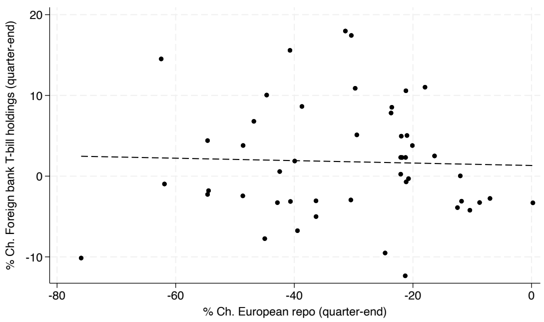
- Figure A3: This figure plots the time series of the repo volumes of European and non-European banks. European banks include all Euro area countries plus the United Kingdom and Switzerland. Major non-European banks are from the United States, Canada and Japan.

- Figure A4: This figure plots the standardized measure of Amihud illiquidity for 1-month T-bills. Higher values correspond to lower T-bill market liquidity. The figure also plots the median value of this measure, which we use to split the sample in some regressions.

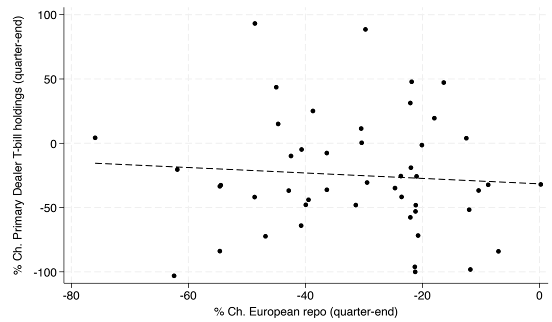
- Table A1 provides results from the first stage regression underlying Table 3.

[37] We only have a detailed breakdown of the term of treasury holdings for foreign banks and primary dealers

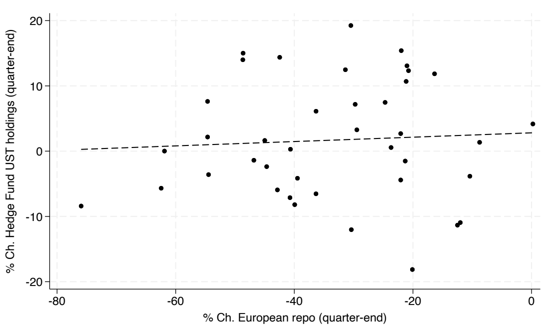
- Table A3: Baseline results (see Table 3) are similar when we used the log of total residual cash over GDP as an explanatory variable in equation (5). Similarly, baseline results remain similar if we construct the 1-month RRP rates using expectations based on the 1-month OIS curve, i.e., $E(RRP(1m) \approx RRP(1-day) + OIS(1-month) - FFR(1-day)$. 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 $\%\Delta$ *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.



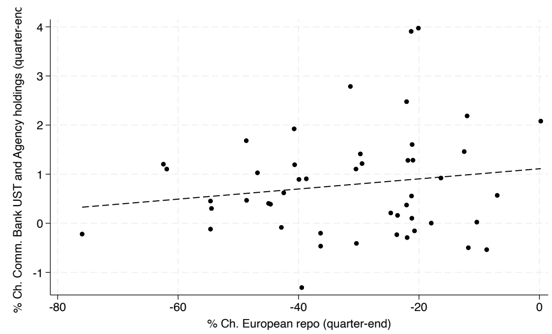
(a) % Ch. Foreign bank T-bill holdings



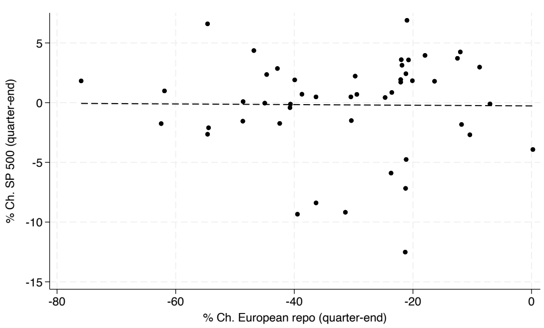
(b) % Ch. Primary Dealer T-bill holdings



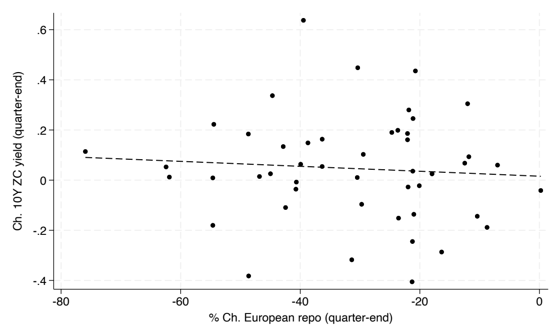
(c) % Ch. Hedge Fund T-bill holdings



(d) % Ch. Commercial Bank US Treasury holdings



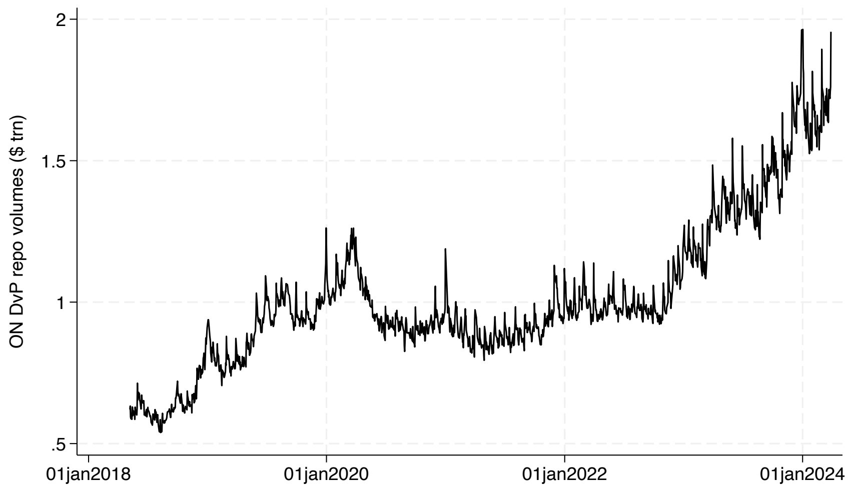
(e) S&P 500 returns



(f) Changes in the 10-year yield

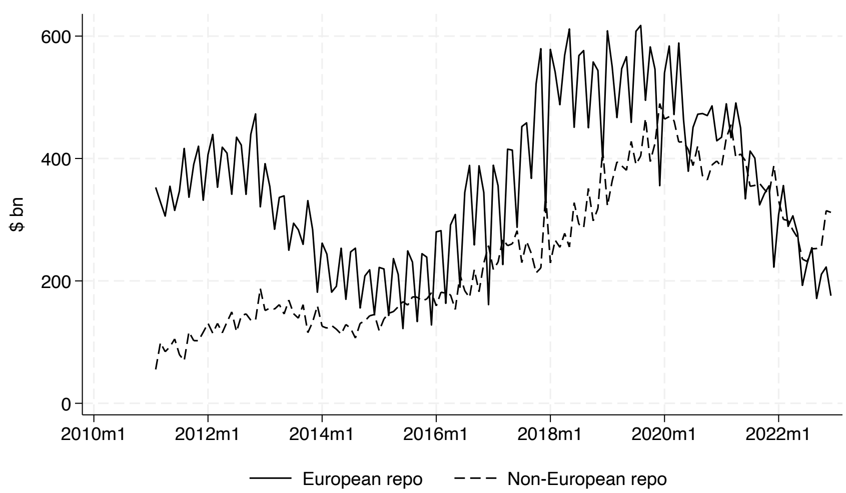
Figure A1: Scatterplot of the instrument $\%\Delta Euro\ repo$ with other variables

Figure A2: Overnight repo volumes at the delivery-versus-payment segment of the repo market



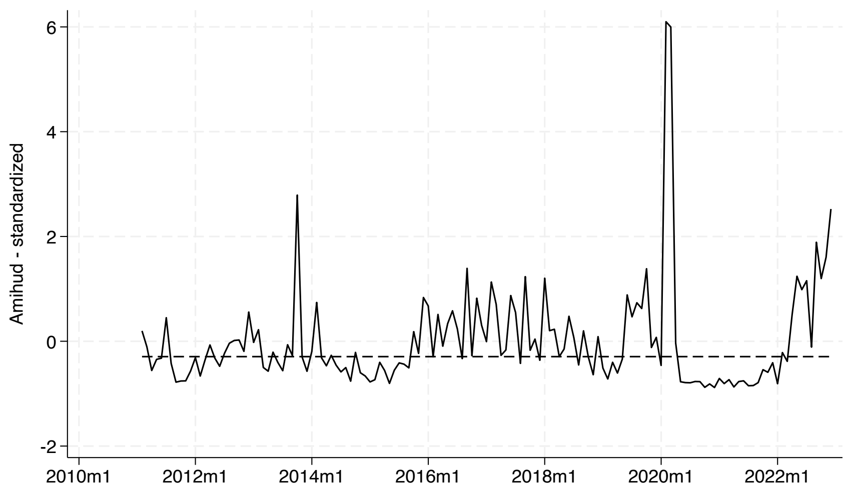
Notes: This figure plots the time series of the overnight repo volumes at the delivery-versus-payment segment of the repo market, which could be a venue the counterparties of European banks could use to replace lost repo funding. Its take-up indeed features spikes at quarter-ends.

Figure A3: Repo volumes of European and non-European banks



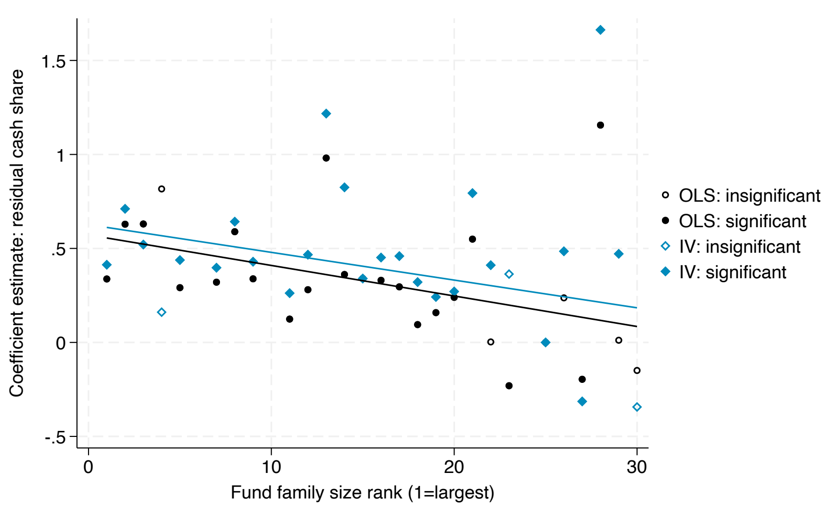
Notes: This figure plots the time series of the repo volumes of European and non-European banks. European banks include all euro area countries plus the United Kingdom and Switzerland. Major non-European banks are from the United States, Canada and Japan.

Figure A4: Time series of the standardized Amihud illiquidity measure



Notes: This figure plots the standardized measure of Amihud illiquidity for 1-month T-bills.

Figure A5: Individual MMF price impact in the T-bill market w.r.t. fund family rank



Notes: This figure plots coefficient estimates from the following OLS (IV) regression in black (blue): $RRP\ (1M) - Tbill\ (1M)_t = \beta\ residual\ cash\ share_{ff,t} + controls_t + \epsilon_t, \quad \beta > 0$ The instruments are the aggregate EU repo change (QE-1,QE) and the fund-family speicifc EU repo change (QE-1,QE). Coefficients significant at the 5% level are shown with solid marker symbols.

Table A1: First stage regressions

VARIABLES	(1) residual cash share	(2) residual cash share	(3) residual cash share	(4) residual cash share	(5) residual cash share
% Ch. European repo (quarter-end)	-0.97***	-1.15***	-0.79***	-0.82***	-1.02***
	(0.17)	(0.27)	(0.18)	(0.26)	(0.23)
FFR	4.09	-4.90	9.89*	-0.83	5.06
	(3.10)	(6.23)	(5.56)	(3.94)	(3.31)
log(bills to GDP)	53.95***	60.54***	15.06	18.54	62.06***
	(10.00)	(10.35)	(54.12)	(31.79)	(11.54)
VIX	0.29	-0.21	0.58***	-0.53	0.25
	(0.25)	(0.60)	(0.22)	(0.68)	(0.23)
Observations	48	25	23	22	26
R-squared	0.51	0.56	0.57	0.48	0.58

Note: This table reports first-stage results for equation (5) underlying Table 3. 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 residual cash share. The main independent variable is %Δ *Euro repo*. In columns (2) and (3), we restrict the sample to periods with above median and below median liquidity in the T-bill market, respectively, based on an Amihud illiquidity measure. Columns (4) and (5) split the sample into periods of low and high concentration in MMF purchases in the Tbill market. Standard errors are robust to heteroskedasticity and autocorrelation using a Bartlett kernel with a bandwidth of 6. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data, FRED, US Treasury.

Table A2: Daily regressions

VARIABLES	(1) T-bill rate	(2) T-bill rate	(3) High Tbill liq T-bill rate	(4) Low Tbill liq T-bill rate	(5) Low Tbill HHI T-bill rate	(6) High Tbill HHI T-bill rate
2 days around QE * Pct. Ch. EU repo	0.13***	0.12***	0.02	0.18***	0.06***	0.21**
	(0.04)	(0.04)	(0.01)	(0.06)	(0.02)	(0.10)
FFR		0.26**	0.95***	0.41***	0.41**	0.33***
		(0.12)	(0.22)	(0.11)	(0.20)	(0.12)
VIX		-0.06	0.15	0.37	-0.10	0.14
		(0.29)	(0.16)	(0.30)	(0.47)	(0.33)
log(bills to GDP)		80.10**	-19.25	151.36***	28.55	115.12***
		(37.96)	(11.82)	(50.75)	(35.64)	(43.96)
days to maturity		-0.22	0.12	-0.43	-0.15	-0.16
		(0.18)	(0.12)	(0.34)	(0.09)	(0.29)
Observations	2,629	2,614	1,452	1,153	1,095	1,429
R-squared	1.00	1.00	1.00	0.99	1.00	0.99
week FE	✓	✓	✓	✓	✓	✓

Note: This table reports results of the regressions with daily frequency. See Section 4.4. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data, FRED, US Treasury.

Table A3: Alternative variable definitions

VARIABLES	(1) OLS RRP-Tbill	(2) 2SLS RRP-Tbill	(3) OLS E(RRP(1M)) - Tbill(1M)	(4) 2SLS E(RRP(1M)) - Tbill(1M)	(5) low bid-ask 2SLS RRP-Tbill	(6) high bid-ask 2SLS RRP-Tbill
residual cash to GDP	3.78***	3.60***				
	(0.77)	(0.93)				
residual cash share			0.38***	0.33***	0.02	0.68***
			(0.08)	(0.09)	(0.06)	(0.23)
FFR	-2.39	0.97	-1.91	1.22	14.29***	3.92*
	(1.54)	(2.59)	(1.74)	(3.10)	(1.64)	(2.11)
log(bills to GDP)	-29.62***	-26.75***	-21.73***	-15.42***	-32.23***	-14.93**
	(4.57)	(6.16)	(3.67)	(3.94)	(10.12)	(6.29)
VIX	-0.14	-0.25	0.13	0.03	0.12	-0.35*
	(0.24)	(0.29)	(0.24)	(0.29)	(0.08)	(0.20)
Observations	143	48	143	48	22	26
R-squared	0.53		0.50			
Effective F-stat		16.38		29.71	51.72	9.37
Anderson-Rubin test (p-val)		0.01		0.01	0.75	0.02
AR 90% CI (lower)		1.90		0.17	-0.08	0.30
AR 90% CI (upper)		5.40		0.51	0.12	1.30

Note: This table reports results for equation (5) using alternative variables. E(RRP(1M)) - Tbill(1M) is constructed using the 1-month OIS curve to reflect expected 1-month RRP instead of realized 1-month RRP. Residual cash to GDP is the aggregate MMF residual cash normalized by GDP. All other variable descriptions are the same as in the main text. Data are at a monthly frequency between February 2011 and December 2022 for OLS regressions and quarterly frequency for 2SLS regressions. Columns (1) and (2) report the results of OLS and 2SLS regressions using residual cash to GDP as opposed to residual cash share in the main text. Columns (3) and (4) report the results of OLS and 2SLS regressions using the E(RRP(1M)) - Tbill(1M) as the dependent variable using expectations of the 1-month RRP rate using the OIS curve instead of the realized one in the main text. The two variables are about 95% correlated. Columns (5) and (6) split the sample into periods of high and low liquidity in the Tbill market, split along the median 1-month bid-ask spread. In 2SLS regressions, we report the effective F statistic as in Olea and Pflueger (2013), the p-value of the Anderson-Rubin test and the confidence intervals based on the inversion of this test (see Andrews et al., 2019). Standard errors are robust to heteroskedasticity and autocorrelation using the Bartlett kernel and a bandwidth of 6. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Source: Crane Data, FRED, US Treasury.

Table A4: Market power in the repo market – controlling for fund size

VARIABLES	(1) rate	(2) rate
F MS bank repo	0.162**	0.163**
	(0.069)	(0.068)
F MS Tbill	-0.319***	-0.337***
	(0.097)	(0.096)
F MS Tbill × Amihud		-0.137***
		(0.047)
F log(size)	0.134	0.137
	(0.124)	(0.124)
Observations	275,331	275,331
R-squared	0.756	0.756
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 (8) controlling for fund size. Variable descriptions and summary statistics can be found in Table 4. 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. 6). *F MS Tbill* (*FF MS Tbill*) is the market share of the fund (fund family) in the T-bill market (see Eq. 7). *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 double clustered at the fund and time level. Source: Crane Data. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A5: Replicating the Huber (2023) results in the sub-sample of overnight repos with US Treasury collateral until December 2017

VARIABLES	(1) rate	(2) FF rate	(3) rate	(4) FF rate	(5) rate	(6) FF rate
F MS bank repo	-0.021					
	(0.082)					
FF MS bank repo		0.026				
		(0.036)				
F bargaining power (repo)			-0.014		-0.011	
			(0.014)		(0.012)	
FF bargaining power (repo)				0.007		-0.001
				(0.017)		(0.010)
Observations	25,664	25,664	25,664	25,664	25,624	25,624
R-squared	0.728	0.729	0.728	0.728	0.774	0.774
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 (8). The sample is restricted to the sample in Huber (2023), i.e., it only covers overnight repos with US Treasury collateral until (including) December 2017. Variable descriptions and summary statistics can be found in Table 4. 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. 6). *F MS Tbill* (*FF MS Tbill*) is the market share of the fund (fund family) in the T-bill market (see Eq. 7). *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. It is standardized to a mean of zero and a standard deviation of one. Standard errors are double clustered at the fund and time level. Source: Crane Data. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

B Theory Appendix

B.1 Derivation of the envelope term $\frac{dU_i}{d\Delta_i}$

Assume an interior second-period optimum $x_i^*(\Delta_i) \in (0,1)$. The period-2 objective is

$$U_i(x_i,\Delta_i) \;=\; x_i\Delta_i\,\rho^T \;+\; (1-x_i)\Delta_i\,\rho^s \;-\; \kappa\big[(1-x_i)\Delta_i\big]^2, \qquad \rho^T \;=\; \bar{\rho} \;-\; \lambda\sum_{j=1}^{F} x_j\Delta_j.$$

By the envelope theorem,

$$\frac{dU_i}{d\Delta_i} \;=\; \frac{\partial U_i}{\partial \Delta_i}\Big|_{x_i=x_i^*(\Delta_i)}.$$

Taking the partial derivative with x_i held fixed (but allowing ρ_T to move with own Δ_i),

$$\begin{aligned} &\frac{\partial U_i}{\partial \Delta_i} = x_i\rho^T \;+\; x_i\Delta_i\frac{\partial \rho^T}{\partial \Delta_i} \;+\; (1-x_i)\rho^s \;-\; 2\kappa(1-x_i)^2\Delta_i, \\ \text{and} \qquad &\frac{\partial \rho^T}{\partial \Delta_i} = -\lambda x_i, \end{aligned}$$

so

$$\frac{\partial U_i}{\partial \Delta_i} = x_i\rho^T \;+\; (1-x_i)\rho^s \;-\; \lambda x_i^2\Delta_i \;-\; 2\kappa(1-x_i)^2\Delta_i.$$

Use the interior FOC for x_i:

$$0 \;=\; \Delta_i(\rho^T-\rho^s) \;+\; x_i\Delta_i\frac{\partial \rho^T}{\partial x_i} \;+\; 2\kappa\Delta_i^2(1-x_i), \qquad \frac{\partial \rho^T}{\partial x_i} = -\lambda\Delta_i,$$

which implies

$$\rho^T-\rho^s \;=\; \lambda x_i\Delta_i \;-\; 2\kappa\Delta_i(1-x_i).$$

Rewrite $x_i\rho^T + (1-x_i)\rho^s = \rho^s + x_i(\rho^T-\rho^s)$ and substitute:

$$\begin{aligned} x_i\rho^T + (1-x_i)\rho^s &= \rho^s + x_i\big[\lambda x_i\Delta_i - 2\kappa\Delta_i(1-x_i)\big] \\ &= \rho^s + \lambda x_i^2\Delta_i - 2\kappa x_i\Delta_i(1-x_i). \end{aligned}$$

Therefore,

$$\begin{aligned}\frac{\partial U_i}{\partial \Delta_i} &= \big[\rho^s + \lambda x_i^2 \Delta_i - 2\kappa x_i \Delta_i (1-x_i)\big] \; - \; \lambda x_i^2 \Delta_i \; - \; 2\kappa (1-x_i)^2 \Delta_i \\ &= \rho^s \; - \; 2\kappa \Delta_i \Big(x_i(1-x_i) + (1-x_i)^2 \Big) \\ &= \rho^s \; - \; 2\kappa \Delta_i (1-x_i),\end{aligned}$$

since $x_i(1-x_i) + (1-x_i)^2 = (1-x_i)[x_i + (1-x_i)] = (1-x_i)$.

Now we focus on the case with homogenous funds and evaluate at the optimal T-bill share $x^*(\Delta)$ from equation (2):

$$x^*(\Delta) = \frac{A + 2\kappa\Delta}{\Delta\,[\lambda(F+1) + 2\kappa]}, \qquad A := \bar{\rho} - \rho^s.$$

Compute $1 - x^*$ and $2\kappa\Delta(1-x^*)$:

$$\begin{aligned} 1 - x^* &= 1 - \frac{A + 2\kappa\Delta}{\Delta[\lambda(F+1) + 2\kappa]} = \frac{\Delta[\lambda(F+1) + 2\kappa] - (A + 2\kappa\Delta)}{\Delta[\lambda(F+1) + 2\kappa]} = \frac{\lambda(F+1)\Delta - A}{\Delta[\lambda(F+1) + 2\kappa]}, \\ 2\kappa\Delta(1-x^*) &= \frac{2\kappa\big[\lambda(F+1)\Delta - A\big]}{\lambda(F+1) + 2\kappa}. \end{aligned}$$

Substitute back to obtain the compact envelope derivative:

$$\begin{aligned}\frac{dU}{d\Delta} &= \rho^s - 2\kappa\Delta(1-x_i^*) \\ &= \rho^s - \frac{2\kappa\big[\lambda(F+1)\Delta - A\big]}{\lambda(F+1) + 2\kappa} \\ &= \rho^s + \frac{2\kappa}{\lambda(F+1) + 2\kappa}\big(A - \lambda(F+1)\Delta\big).\end{aligned}$$

B.2 Proof of Proposition 3.4

$$\Delta(r,\xi) = 1 - C\,r^{-\xi}, \qquad \mu(\xi) = \frac{\xi}{\xi - 1}, \qquad H = \lambda(F+1), \qquad \phi = \frac{2\kappa}{H + 2\kappa}, \qquad A := \bar{\rho} - \rho_s > 0.$$

$$r^* = \mu(\xi)\Big[\rho_s + \phi\big(A - H\,\Delta(r^*,\xi)\big)\Big].$$

$$F(r;\xi) := r - \mu(\xi)\Big[\rho_s + \phi\big(A - H\,\Delta(r,\xi)\big)\Big], \qquad F(r^*;\xi) = 0.$$

$$\frac{\partial \Delta}{\partial r}(r,\xi) = C\,\xi\,r^{-(\xi+1)}, \qquad \frac{\partial \Delta}{\partial \xi}(r,\xi) = C\,r^{-\xi}\ln r, \qquad \mu'(\xi) = -\frac{1}{(\xi-1)^2} < 0.$$

Hence

$$F_r(r;\xi) = 1 - \mu\,\phi\,H\,\frac{\partial \Delta}{\partial r} = 1 + \mu\,\phi\,H\,C\,\xi\,r^{-(\xi+1)} \;>\; 0.$$

Hence, the fixed point is unique and differentiable, and by the implicit function theorem:

$$\frac{\partial r^*}{\partial \theta} = -\frac{F_\theta}{F_r}\bigg|_{r=r^*}, \qquad \theta \in \{\xi, \lambda\}.$$

$$H'(\lambda) = G > 0, \qquad \phi'(\lambda) = \frac{d}{d\lambda}\frac{2\kappa}{H(\lambda)+2\kappa} = -\frac{2\kappa\,G}{\big(H(\lambda)+2\kappa\big)^2} < 0.$$

Holding r fixed,

$$\begin{aligned}
F_\lambda(r;\mu,\lambda) &= -\mu\frac{d}{d\lambda}\Big\{\phi(\lambda)\big(A - H(\lambda)\Delta(r)\big)\Big\} \\
&= -\mu\Big[\phi'(\lambda)\big(A - H(\lambda)\Delta(r)\big) + \phi(\lambda)\big(-H'(\lambda)\Delta(r)\big)\Big] \\
&= \mu\,\frac{2\kappa G}{\big(H(\lambda)+2\kappa\big)^2}\Big[(A - H\Delta(r)) + \big(H(\lambda)+2\kappa\big)\Delta(r)\Big] \\
&= \mu\,\frac{2\kappa G}{\big(H(\lambda)+2\kappa\big)^2}\Big(A + 2\kappa\,\Delta(r)\Big) \;>\; 0.
\end{aligned}$$

Therefore

$$\frac{\partial r^*}{\partial \lambda} = -\frac{F_\lambda}{F_r}\bigg|_{r^*} = -\frac{\mu\,\dfrac{2\kappa G}{\big(H(\lambda)+2\kappa\big)^2}\Big(A + 2\kappa\,\Delta(r^*)\Big)}{1 + \mu\,\phi(\lambda)\,H(\lambda)\,C\,\xi\,r^{*-(\xi+1)}} \;<\; 0.$$

Conclusion: The equilibrium repo rate r^* is strictly decreasing in λ (T-bill price impact).

$$F_\xi(r;\xi) = -\mu'(\xi)\Big[\rho_s + \phi\big(A - H\,\Delta(r,\xi)\big)\Big] + \mu(\xi)\,\phi\,H\,\frac{\partial\Delta}{\partial\xi}(r,\xi)$$
$$= -\mu'(\xi)\Big[\rho_s + \phi\big(A - H\,\Delta(r,\xi)\big)\Big] + \mu(\xi)\,\phi\,H\,C\,r^{-\xi}\ln r.$$

$$F_\xi(r^*;\xi) = -\frac{\mu'(\xi)}{\mu(\xi)}\,r^* + \mu(\xi)\,\phi\,H\,C\,r^{*-\xi}\ln r^*.$$

$$\frac{\partial r^*}{\partial\xi} = -\frac{F_\xi}{F_r}\bigg|_{r^*} = \frac{\dfrac{\mu'(\xi)}{\mu(\xi)}\,r^* \;-\; \mu(\xi)\,\phi\,H\,C\,r^{*-\xi}\,\ln r^*}{1 + \mu(\xi)\,\phi\,H\,C\,\xi\,r^{*-(\xi+1)}} \;<\; 0$$

Conclusion: The equilibrium repo rate r^* is strictly decreasing in the bank demand elasticity for repos ξ.