Mutual Fund Liquidity Transformation and Reverse Flight to Liquidity*

Yiming Ma†
Columbia Business School

Kairong Xiao‡
Columbia Business School

Yao Zeng§
Wharton

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†Finance Division, Columbia Business School, 3022 Broadway, Uris Hall 820, New York, NY 10027. E-mail: `ym2701@gsb.columbia.edu`.

‡Finance Division, Columbia Business School, 3022 Broadway, Uris Hall 822, New York, NY 10027. E-mail: `kairong.xiao@gsb.columbia.edu`.

§Wharton School, University of Pennsylvania, Steinberg-Dietrich Hall 2300, Philadelphia, PA 19104. E-mail: `yaozeng@wharton.upenn.edu`.

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Abstract

Traditionally liquid asset markets, such as those for Treasuries and high-quality corporate bonds, were strained by unusually high selling pressures during the Covid-19 pandemic, which contrasts with the flight to liquidity observed in past crises. We identify the increased role of fixed-income mutual funds in liquidity transformation as an important contributing factor to this phenomenon. Mutual funds issue demandable equity that exposes investors' redemption value to fluctuations in economic fundamentals. With a large negative shock to economic fundamentals in the Covid-19 crisis, concerns about economic fundamentals coupled with asset illiquidity lead to pronounced outflows from fixed-income mutual funds. Because funds follow a pecking order of liquidation by first selling more liquid assets before moving on to more-illiquid ones, fund outflows generated concentrated selling pressures in traditionally *more liquid* asset markets. Investors' flight out of fund shares was thereby turned into the observed *reverse flight to liquidity.* The purchase of risky securities by the central bank may serve as an important policy tool for stabilizing liquidity transformation and liquid asset markets.

1 Introduction

The Covid-19 pandemic has led to widespread distress in funding markets. Uncertainty in the pandemic's trajectory and the speed of economic recovery sparked concerns over companies' credit quality, which caused a scramble amongst investors to reduce their exposure to illiquid corporate debt. However, the impact was not limited to risky corporate debt. Markets for traditionally liquid assets, such as those for Treasuries and high-quality corporate bonds, experienced significant strains from unusually high *selling* pressures before extensive intervention by the Federal Reserve. This observation is surprising in light of the flight to liquidity phenomenon generally seen in crises, which would suggest *buying* pressures in high-quality liquid asset markets

We find that the increased role of fixed-income mutual funds in liquidity transformation contributed to the reverse flight to liquidity phenomenon observed in financial markets during the Covid-19 crisis. Fixed-income mutual funds have continuously grown in size over the past decades as shown in Figure 1. By the end of 2019, the amount of redeemable shares issued by fixed-income mutual funds amounted to 35% of the banking sector's deposits. Similar to banks, fixed-income mutual funds provide liquidity by pooling idiosyncratic liquidity risk across investors so that a larger share of illiquid assets in their portfolio can be held until maturity (Ma, Xiao and Zeng, 2019). At the same time, mutual funds issue demandable equity that exposes investors' redemption value to continuous fluctuations in economic fundamentals.

When the Covid-19 pandemic brought about a large negative shock to economic fundamentals, investors concerned about the performance and illiquidity of fund assets redeemed their shares en masse, resulting in unprecedented outflows in March 2020 (see Figure 2). In meeting redemption requests, mutual funds followed a pecking order of liquidation by first selling their most liquid assets before more illiquid ones in order to minimize the discounts from asset sales, which is why the pronounced outflows lead to concentrated selling pressure in some of the traditionally *most liquid* asset markets. Within the first quarter of 2020, the mutual fund sector sold off $236 billions of Treasury securities, which contributed to the large volatility and price discounts in Treasury markets.

The reverse flight to liquidity phenomenon is a distinctive feature of liquidity transformation by demandable-equity issuing mutual funds. A large fraction of financial intermediation has migrated away from banks over the past decades and especially since the 2008 financial crisis

(Ma, Xiao and Zeng, 2019). The increased reliance on mutual funds in liquidity transformation contributed to the salience of the reverse flight to liquidity phenomenon during the Covid-19 crisis relative to previous crises.

Our findings inform the debate on the merits of corporate bond purchases by the Federal Reserve. Traditionally, the Federal Reserve has been limited to purchasing relatively safe assets such as Treasuries and mortgage-backed securities. The unprecedented expansion of asset purchases into corporate bonds during the Covid-19 crisis raises important questions regarding the role of similar policy tools going forward.[1] We show that the announcement of purchasing illiquid bonds significantly alleviated fund outflows to reduce asset sales that strained liquid asset markets. In contrast, the purchase of liquid securities like Treasuries was less effective because it only "cleaned-up" by buying securities being sold instead of alleviating outflows through improving expected economic fundamentals. Going forward, since mutual funds lack direct access to central bank liquidity facilities, central bank interventions in more illiquid asset classes may become an effective liquidity backstop for stabilizing liquidity transformation.

We take several steps to arrive at our results. We first examine overall asset price movements In March 2020. We find that unlike in past crisis episodes, Treasury yields were higher when market volatility was higher during the Covid-19 crisis (Figure 3). This suggests that the pressure to sell Treasuries was higher when markets were more stressed, which points to a *reverse flight to liquidity* rather than the usual *flight to liquidity* that would involve a net pressure to buy into safe and liquid assets like Treasuries. Further, Treasuries were trading at substantial discounts over their implied prices from interest rate expectations and sovereign default, suggesting that the selling pressures must arise for other reasons. Finally, in line with the literature, we also find evidence for heightened selling pressure in high-quality corporate bond markets, where bond prices fell more than what default risks could explain (see Figure 5).

The disruptions in traditionally liquid asset markets occurred at the same time as bond mutual funds suffered unprecedented outflows as shown in Figure 6. Outflows and asset liquidations were much smaller at equity funds, which is suggestive of asset illiquidity being an important amplifier of outflows. Within the fixed-income fund sector, those specializing in more illiquid asset classes such as bank loan funds and high yield corporate funds also experienced larger outflows than investment grade and government funds, which again points to the important role of liquidity

[1] For instance, see Financial Times April 12 article "Federal Reserve has encouraged moral hazard on a grand scale". See also Bloomberg June 4 article "A Rally Running on Moral Hazard Looks Like the Fed's Latest Feat".

transformation. Although outflows at illiquid funds were larger, it was the most liquid assets in their portfolios such as Treasuries and high-quality corporate bonds were disproportionately sold, which is in line with the large selling pressures in these liquid asset market. The aggregate sale volume of liquid securities by the fund sector was large. For example, mutual funds sold $236 billion in Treasuries in 2020Q1, which is the highest among different types of financial institution.

We develop a conceptual framework to shed light on the economic mechanisms at play and to guide our empirical analysis. In the model, which we detail in the appendix, mutual funds transform liquidity by pooling idiosyncratic liquidity liquidity risks across investors. They issue redeemable shares to investors backed by a portfolio of illiquid assets and liquid assets. When investors' expectations about future economic fundamentals deteriorate, their upside of staying with the fund and benefiting from the long-run return of the funds' assets declines. To reduce losses from early liquidations, the fund chooses to meet redemption requests by first selling the more liquid asset before tapping into illiquid assets that incur steeper liquidation discounts. Therefore, as negative signals about economic fundamentals emerge and redemption requests increase, the fund's pecking order of liquidations leads to more concentrated sales in the more liquid asset. Investors' flight to liquidity is thereby turned into the mutual fund's reverse flight to liquidity.

The magnitude of outflows and liquidations in reverse flight to liquidity episodes increases with fund liquidity transformation. When funds transform more illiquid assets into liquid shares, the stickiness of their share value (NAV) increases. NAV stickiness exacerbates investors' redemption incentives because a larger proportion of liquidation costs are born by those that choose to remain in the fund. In addition to suffering from more pronounced outflows, funds that specialize in more illiquid asset classes also have a larger demand for holding liquid assets as a buffer. As a consequence, their capacity to engage in the sale of liquid assets in the event of redemption shocks increases.

We empirically confirm the intricate relationship between fund liquidity transformation and the reverse flight to liquidity phenomenon during the Covid-19 crisis using granular data on fund-level flows and portfolio holdings. First, we find that outflows were more pronounced at fixed-income funds that invested in more illiquid assets and engaged in more liquidity transformation. Controlling for a range of fund characteristics and fund-type fixed effects, we find that a one standard deviation increase in liquidity transformation before the Covid-19 crisis lead to a 0.8%

increase in fund outflows in March 2020. The economic impact of liquidity transformation on fund outflows is amongst the highest across all other observable fund characteristics, which confirms the contribution by fund liquidity transformation to fund outflows given a shock to economic fundamentals.

Further, liquid securities were more prone to be liquidated in response to fund outflows, consistent with the observed reverse flight to liquidity during the Covid-19 crisis. We find that the sensitivity of fund-level liquidations of individual corporate bonds to redemptions at the same fund increases with the rating of the bond. In other words, more liquid corporate bonds are more likely to suffer liquidation pressures from fund outflows while less liquid corporate bonds suffer liquidation pressure only when outflows are large enough. Importantly, this pattern is salient only at actively managed open-end funds but not at index mutual funds, whose portfolio choices are constrained by their investment mandate. Hence, funds chose to use a pecking order of liquidations to meet redemption requests when they had the option to do so.

Eventually, the large outflows at funds and the concentrated sale of liquid assets from funds' balance sheets trickled down to aggregate asset prices. We find that returns of Treasury notes, Treasury bonds, and investment-grade corporate bonds that were held by funds suffering larger outflows also experienced larger drops in returns within bonds by the same issuer. The lack of price impact for high-yield bonds is consistent with funds first selling their more liquid assets to meet redemption requests. We further confirm that bonds higher up in the liquidation order of funds suffer larger drops in returns in response to outflow, controlling for both issuer fixed effects and time-varying maturity and ratings fixed effects. Magnitude wise, a 1% increase in fund outflows leads to a 1.6 bps drop in returns for bonds with a below-median liquidity ranking but a 5 bps drop in returns for bonds with an above-median liquidity ranking. The difference in returns to flow sensitivity is both statistically and economically significant.

Finally, we shed light on how central bank interventions can help stabilize mutual fund liquidity transformation and mitigate potential strains in liquid asset markets. Unlike banks that have access to several liquidity backstops from the central bank, mutual fund liquidity transformation is conducted largely outside of the central bank's safety net. The announcement of corporate bond purchases on March 23 and April 9 marked unprecedented support to the mutual fund sector by the Federal Reserve. We find that the announcement to purchase corporate bonds to include recently downgraded junk bonds had the largest impact on alleviating fund outflows and costly asset liquidations compared to other interventions like the purchase of Treasury securities. Through the lens of our model, the announcement of future bond purchases improves expectations about fund asset returns, and thereby curbs outflows from the outset, whereas the purchase of Treasury securities can only reduce the discount on selling Treasuries in meeting redemptions. Therefore, central bank interventions in traditionally less-liquid asset classes may become an effective tool for ensuring the smooth functioning of traditionally liquid financial markets and liquidity transformation beyond the banking sector.

Related Literature. Through analyzing mutual fund liquidity transformation and its implications on asset markets, we provide a plausible explanation for the illiquidity and volatility in traditionally liquid asset markets during the Covid-19 crisis: the increased reliance on liquidity transformation by mutual funds that turned investors' flight to liquidity into an aggregate reverse flight to liquidity by open-end fixed-income mutual funds. Thus, our study contributes to the understanding of the liquidity events in financial markets during the Covid-19 crisis.

Schrimpf, Shin and Sushko (2020) and Fleming and Ruela (2020) first document the unusual drop in liquidity and increase in volatility in Treasury markets, and Kargar, Lester, Lindsay, Liu, Weill and Zuniga (2020) find similar spikes of illiquidity in corporate bond markets. Haddad, Moreira, and Muir (2020) identfy strains in high-quality segments of corporate bonds and bond ETFs. Liang (2020) and Vissing-Jorgensen (2020) provide a more detailed review and additional insights on the market developments and their potential mechanisms.

In explaining the debt market disruptions, Duffie (2020) and He, Nagel, and Song (2020) focus on the demand side and show that dealers' balance sheet constraints strained their ability to absorb the heightened selling pressure in Treasury markets. Kargar, Lester, Lindsay, Liu, Weill and Zuniga (2020) and O'Hara and Zhou (2020) show that the shift from principal to agency trading by dealers has contributed to illiquidity in corporate bond markets, despite the increase in costly electronic customer trading.

We analyze a complementary channel from the supply side by identifying mutual funds as a dominant seller of liquid assets that contributed to their eventual illiquidity. Our focus on the patterns of asset liquidation by mutual funds and their corresponding asset pricing implications also complements Falato, Goldstein and Hortacsu (2020), who examine various sources of fragility in fixed-income mutual fund flows. Consistent with liquidity transformation being an important amplifier of fund outflows, Pastor and Vorsatz (2020), analyze the performance of equity mutual funds and find only modest outflows from active equity funds, mostly driven by small-cap funds. Finally, Schrimpf, Shin and Sushko (2020) point to hedge funds' unwinding of Treasury positions as a another source of selling pressures in Treasury markets.

More generally, our paper relates to a growing literature on mutual fund flows and their financial stability implications. Chen, Goldstein and Jiang (2010) and Goldstein, Jiang and Ng (2017) find that funds' flow-to-performance relationship is more concave when the funds in question hold more illiquid assets. We focus on the need for mutual funds to hold liquid buffers as part of their liquidity transformation and demonstrate the consequences on asset markets as mutual funds' liquid asset buffers are deployed. In this sense, our findings generalize the importance of cash as a liquidity buffer shown by Chernenko and Sunderam (2017) to a range of asset classes beyond cash. Our findings also reconcile Choi, Hoseinzade, Shin and Tehranian (2019) and Jiang, Li and Wang (2020), who focus on mutual fund portfolio management and find little direct price impact by mutual fund outflows on illiquid asset markets. Rather than focusing on the price impact on illiquid bonds, we analyze portfolio changes in general and find more significant selling pressure for the more liquid end of the asset spectrum. Consistent with our findings, Huang, Jiang, Liu and Liu (2020) find that Treasury pairs commonly held by bond funds exhibit higher return co-movement.

Our results also speak to the consequences of financial intermediation and liquidity transformation by non-banks. The traditional intermediation literature has mostly focused on deposit-issuing commercial banks in liquidity provision, e.g., Diamond and Dybvig (1983), Diamond and Rajan (2001), Kashyap, Rajan and Stein (2002), and Goldstein and Pauzner (2005). More recent papers have increasingly considered the effect of non-banks in providing financial intermediation services. Hanson, Shleifer, Stein and Vishny (2015) consider debt claims issued by both banks and shadow banks that differ in their access to deposit insurance.[2] Ma, Xiao and Zeng (2019) provide a unified framework to show that both debt-issuing and equity-issuing intermediaries provide liquidity. We analyze the effects of mutual fund liquidity transformation on liquid asset markets and evaluate the effectiveness of central bank policy in stabilizing liquidity transformation.

The remainder of the paper is arranged as followed. Section 2 explores aggregate trends in asset prices and the behavior of mutual funds in the Covid-19 pandemic. Section 3 further

[2]Other papers on shadow bank liquidity provision include Gorton and Metrick (2010), Stein (2012), Sunderam (2015), Nagel (2016), Moreira and Savov (2017) and Xiao (2020).

explores fund-level and bond-level variation to show how mutual fund liquidity transformation contributed to the recent reverse flight to liquidity phenomenon. We discuss our results in the context of a simple theoreticaly framework, which we detail in Appendix A. Section C examines interventions by the Federal Reserve and its effects on mutual fund flows and NAVs. Finally, Section 5 concludes the paper and discusses policy implications going forward.

2 Aggregate Trends

We begin by looking at asset prices and the overall behavior of the fixed-income mutual fund sector in the first half of 2020, focusing on the developments in March and April. The beginning of March was when community spread of Covid-19 within the US became evident and significant damage to the real economy was expected from the impending social distancing measures. Starting from the latter half of March, market conditions became jointly influenced by the Federal Reserve's widespread policy interventions, which we will examine in Section 4.

2.1 Asset Market Disruptions

Generally, safe and liquid assets like US Treasuries are thought to be in demand during crisis periods that are marked by high market volatility. Such a flight to liquidity episode was evident during the 2008 financial crisis for example, when Treasury yields dropped on days when market volatility surged (see Figure 3).

In contrast, Treasury markets during the Covid-19 crisis experienced disruptions from a heightened pressure to sell rather than to buy. From the blue dots in the top panel of Figure 3, we see that the relationship between Treasury yields and VIX remains negative in January and February of 2020, which was before the widespread global spread of the pandemic. Starting in March and lasting through April however, the relationship reversed. Days on which market volatility was higher also had higher Treasury yields (red dots). This trend implies that worsening economic conditions and volatility coincided with a higher pressure to sell Treasuries, which depressed Treasury prices and lead to a surge in Treasury yields. In other words, there was *reverse flight to liquidity* during the Covid-19 period instead of the usual flight to liquidity.

To confirm that the reverse flight to liquidity phenomenon was not driven by unusual changes in interest rate risk and credit credit of Treasuries but by heightened selling pressure, we analyze the behavior of the CDS-adjusted Treasury swap spread. This spread is calculated by subtracting the Treasury yield from the sum of the interest swap rate and the US sovereign CDS rate of the same maturity. From the upper panel of Figure 4, we see that the CDS-adjusted Treasury swap spread dropped significantly in the first half of March. This trend implies that Treasury yields spiked to levels beyond what interest rate risk and credit risk could explain with the onset of the Covid-19 crisis in the U.S., consistent with there being net selling pressures for other reasons.

The pressure to sell Treasuries was so high that the volatility in 10-year Treasury Notes, which is an indicator for market strains, increased by 10% within the first half of March as shown in the lower panel of Figure 4. Other Treasury market indicators also revealed significant strains during this time as shown by Fleming and Ruela (2020).

The net pressure to sell liquid assets was not only confined to the Treasury market. Deteriorating corporate fundamentals also lead to a surge in both corporate CDS rates and corporate bond yields, albeit to a different extent. Following Haddad, Moreira, and Muir (2020), we plot the evolution of the CDS-bond basis in the upper panel of Figure 5. The CDS-bond basis , which is the difference between the CDS spread and the bond spread, plunged drastically from a stable -10 basis points to below -35 basis points for both high yield and investment grade bonds. The divergence between CDS spreads and corporate bond spreads indicates that the pressure to sell corporate bonds became so high that markets became too strained to close the arbitrage.

Another observation from Figure 5 is that the CDS-bond basis widening was at least as pronounced for investment-grade bonds than for high-yield bonds for the majority of the time before interventions by the Fed.[3] This trend is also consistent with the results in Haddad, Moreira, and Muir (2020), Boyarchenko, Kovner and Schachar (2020), Kargar, Lester, Lindsay, Liu, Weill and Zuniga (2020), and O'Hara and Zhou (2020).

Echoing the previous discussion on flight to liquidity, selling pressures in high-quality and traditionally more liquid corporate bonds were surprising because investors wanting to reduce their direct exposure to the pandemic should be more inclined to sell the riskier high-yield bonds. As we will show, the selling pressure for Treasuries and high-quality corporate bonds during the

[3]This observation also suggests that the CDS-bond basis widening cannot be driven by an increase in the cost of dealers' balance sheet space alone, which should generally apply to all trades.

Covid-19 crisis are intricately related because both are held as liquid asset buffers by bond mutual funds to carry out liquidity transformation.

2.2 Mutual Fund Outflows and Liquidations

We argue that it is the increased reliance on fixed-income mutual funds in liquidity transformation that has generated pronounced redemptions by investors and concentrated sales in traditionally liquid asset markets during the Covid-19 crisis. The fixed-income mutual fund sector has experienced an explosive growth spurt over the past decades, and especially since the 2008 financial crisis. The total asset size of fixed-income mutual funds has increased from less than $1 trillion in 2000 to more than $4.5 trillion by the end of 2019 (see upper panel of Figure 1). Their growth rate has exceeded that of the banking sector and by the end of 2019, fixed-income mutual fund shares amounted to almost 35% of deposits issued by the banking sector (see lower panel of Figure 1). At the same time, they have become one of the most important intermediaries investing in corporate bonds, and hold more than 20% of all outstanding corporate bonds in 2019. Taken together, fixed-income mutual funds have for the first time become a significant player in the US financial system at the onset of the Covid-19 recession relative to previous crisis episodes.

At the same time, the fixed-income mutual fund sector suffered unprecedented outflows when heightened selling pressures emerged in liquid asset markets. In March 2020, it lost an unprecedented $264 billion of assets under management as shown in the upper panel of Figure 2. In comparison, equity mutual funds, whose assets were also exposed to the worsening real economy but are more liquid than corporate bonds, were subject to much smaller outflows as shown in the lower panel of Figure 2. The difference in outflows between equity and bond funds provides first evidence that the transformation of illiquid assets into liquid fund shares exacerbates fund outflows.

The amplifying effect of asset illiquidity on outflows is also confirmed by the behavior of different types of fixed-income funds. Before intervention by the Federal Reserve, cumulative outflows increase in magnitude from Government bond funds to corporate bond funds to loan funds. Quantitatively, cumulative outflows at investment-grade, high-yield, and loan funds averaged to 1.6%, 5.6%, and 11.6% from January, 2020 to March 15, 2020 (Figure 6).

However, if funds liquidated assets proportionately to meet redemptions, larger outflows at funds holding lower-quality and more-illiquid assets would be at odds with selling pressures concentrated in Treasuries and other high-quality liquid assets. Indeed, we find that fixed-income funds disproportionately sold the most liquid components of their portfolios to pay redeeming investors. As Figure 7 shows, holdings of Treasuries decreased by 11% in March 2020 while holdings of AAA and AA+ rated corporate bonds decreased by around 5%. The position changes in lower-rated bonds is smaller and generally decreasing in ratings, confirming that liquid assets in bond funds' portfolios were disproportionately sold off.

In aggregate, the volume of Treasuries sold by open-end mutual funds is economically significant at $236 billion in the first quarter of 2020 (see Figure 8 and Table 1). Compared to other financial institutions in the Flow of Funds, the large sale of liquid assets appears unique to the mutual fund sector. In particular, other financial intermediaries that provide liquidity, such as commercial banks, did not engage in a net sale of Treasury securities during the same period. Relative to Treasury liquidations by other non-financial sectors, liquidations by mutual funds are only below that of the rest of the world ($287 billion) in absolute terms. As a proportion of Treasuries held at the end of 2019Q4, mutual funds experience the largest decline at 18%.[4]

Taken together, the aggregate trends in this section provide preliminary evidence that there were pronounced outflows at fixed-income mutual funds and that funds disproportionately sold more liquid assets, which ultimately led to a systematic sell-off of liquid assets by the mutual fund sector. The magnitude of this phenomenon appeared to be unique to the mutual fund sector amongst all other financial intermediaries and occurred at around the same time as heightened selling pressures emerged in traditionally liquid asset markets. Mutual funds with more illiquid portfolios were most exposed, which suggests an amplifying effect of mutual fund liquidity transformation on the risk of concentrated outflows and sell-offs of traditionally liquid assets.

3 Empirical Analysis

This section contains our main empirical analysis. We begin by demonstrating that funds providing more liquidity also suffered higher outflows during the Covid-19 crisis. Then, we show that

[4]Sector-level data is only available as of 2020Q1 from the Flow of Funds, which may already include the impact of some interventions by the Federal Reserve. The quoted Treasury sales volumes are therefore likely an underestimate of the peak sales that occurred during the Covid-19 crisis.

funds displayed a pattern of selling more liquid assets first. Finally, we confirm that liquid assets held by funds with greater outflows indeed suffered larger drops in returns. In each subsection, we also discuss the intuition of the empirical results in relation to our theoretical framework. For details of the model, please refer to Appendix A.

3.1 Data

Mutual fund data. We merge the CRSP Mutual Fund Database and Morningstar Database to create a sample of open-end US fixed-income mutual funds. For each fund, we observe its daily fund flows, portfolio returns, assets under management, and quarter-end securities holdings. The sample period is from January 1, 2020 to April 30, 2020. Table 2 presents the summary statistics of the mutual fund sample as of March 2020. Our sample contains 6,356 unique share classes and 1,942 funds.

Security-level data. We obtain daily security-level data on prices of Treasury and corporate bonds from CRSP U.S. Treasury Database and TRACE. We complement these two databases with interest swap rates and sovereign and corporate CDS spreads retrieved from Bloomberg. We further obtain characteristics of corporate bonds such as maturity and ratings from the Mergent-FISD Database.

We calculate mutual fund-induced outflows for each bond based on funds' portfolio holdings. Specifically, for each bond, we compute daily imputed outflows by taking a weighted average of outflows at funds that held this bond at the end of 2019Q4, where weights are defined by the volume of the holdings. Formally, the imputed flow of bond i at date t is given by

$$\text{Imputed outflow}_{i,t} = \sum_j \text{Fund outflow}_{j,t} \times \frac{\text{Holding}_{i,j,2019Q4}}{\sum_k \text{Holding}_{i,k,2019Q4}}, \tag{3.1}$$

where $\text{Holding}_{i,j,2019Q4}$ is the holding of bond i by fund j in 2019Q4.

We also calculate a liquidation rank for each bond i held by fund j as the share of bonds i' that are held by fund j and incur a higher liquidation discount (i.e. less liquid) than bond i:

$$\text{Rank}_{i,j} = \sum_{i'} \text{Share}_{i',j} \times \mathbb{1}\left[\text{Liquiditation Discount}_i < \text{Liquidation Discount}_{i'}\right] \tag{3.2}$$

Since bond-level liquidation discounts are difficult to measure, we sort by liquidation discounts of bond categories. Treasury bills, Treasury notes, and Treasury bonds come first. Corporate bonds sorted by decreasing ratings follow thereafter, i.e. AAA, AA+, AA, AA-......

Commercial bank data. We obtain data on commercial banks from Call Reports from 2019Q1 to 2020Q1. For each bank, we observe quarterly deposit flows and portfolio composition by asset class. To compare loan funds against commercial banks, we select a subset of commercial banks similar to loan funds in terms of their asset composition to form a matched sample. Specifically, for each loan fund, we choose a bank with similar cash, government bonds, and loan holdings as of 2019Q1.

Haircut Data. We obtain time-series data on repo haircuts by asset category from the New York Federal Reserve.

3.2 Liquidity Transformation and Fund Outflows

As shown in Figure 2 of Section 2, fixed-income mutual funds faced significant outflows during the Covid-19 pandemic. Our model suggests that funds specializing in more illiquid assets should suffer more pronounced outflows because of their more sticky NAVs (Proposition 2). When investors redeem shares from a fund, the fund liquidates assets at a cost to meet their redemption requests. When fund NAVs are more sticky, a small proportion of the costs from premature asset liquidations will be incorporated in the end-of-day NAV while more of it will be incorporated in the future NAV. The incentive to redeem early before the NAV has fully captured liquidation losses is therefore higher when NAV stickiness is larger, leading to more pronounced outflows at funds with illiquid assets with lower NAV flexibility.

One proxy for NAV stickiness is the average illiquidity of funds' asset portfolio, which we calculate as the weighted average of haircuts incurred by $1 invested in the fund's portfolio. A binned-scatter plot of fund outflows in March 2020 against fund's asset illiquidity in 2019Q4 (see upper panel of Figure 9) shows that outflows are indeed more pronounced for funds invested in more illiquid assets.

Funds' asset illiquidity is closely tied to their liquidity transformation because it is the illiquid assets (on the asset side of the balance sheet) that are transformed into liquid fund shares (on the liability side of the balance sheet). Specifically, we measure liquidity transformation using the Liquidity Provision Index (LPI) proposed by Ma, Xiao and Zeng (2019). Intuitively, the LPI captures how much more can be obtained by redeeming shares from the fund relative to the direct liquidation value of the underlying assets. Repeating the same binned-scatter plot of outflows against fund LPI, we find that higher fund liquidity transformation indeed comes at the expense of larger outflows (see lower panel of Figure 9).

$$\text{Outflows}_j = \beta \text{Asset Illiquidity}_j + \gamma \text{Controls}_j + \epsilon_j$$

Recognizing that funds may differ along dimensions other than their asset illiquidity, we further regress cumulative outflows for fund j in March 2020 against fund j's asset illiquidity while controlling for a number of fund characteristics including volatility, return, yield, expense ratio, and turnover ratio as of 2019Q4 (see Table 3). We further include a fixed effect for different investment objectives so our results should be interpreted as a within fund-type effect that absorbs differences in fundamentals across asset classes. Notably, the coefficient on asset illiquidity remains significant at the 1% level regardless of how the model is saturated with controls and fixed effects, and the fit of the model is only minimally improved with the addition of explanatory variables. Magnitude wise, when asset illiquidity increases by one standard deviation, outflows increase by 0.6% in the most restrictive specification.

$$\text{Outflows}_j = \beta \text{LPI}_j + \gamma \text{Controls}_j + \epsilon_j$$

We repeat the same specification with fund LPI an place of fund illiquidity in Table 4 and find very similar statistical and economic significance. In particular, when fund LPI increases by one standard deviation, outflows increase by 0.8% in the most restrictive specification. Taken together, these results corroborate the strong interdependence between fund liquidity transformation and the outflows.

3.3 Pecking Order of Liquidation

Pronounced outflows alone cannot explain why selling pressure emerged in the most liquid types of assets. Funds' strategies on which assets to sell also play a vital role. Proposition 1 shows that the optimal strategy in meeting redemption requests is to sell more-liquid assets before more-illiquid ones. The reason is that more liquid assets suffer lower liquidation discounts when prematurely sold so that selling them first can help minimize the losses from early liquidations. Our model captures a one-off shock to expected economic fundamentals. We believe that it matches the context of the Covid-19 crisis well, which was also posed an unexpected and acute shock to firms' cashflows and hence the expected performance of their debt securities that are held by funds. Nevertheless, there could also be dynamic incentives against a full pecking order when shocks are persistent or uncertain in nature that would encourage funds to preserve their liquid asset buffer for future use. Therefore, to what extent funds follow the pecking order of liquidations is an empirical question, which we examine below using a range of fund and bond level analysis.

$$\text{Liquidation}_{i,j} = \beta \text{Outflows}_j + \gamma \text{Controls}_{i,j} + \epsilon_{i,j}$$

We first examine how the sensitivity of liquidations for a given security varies with respect to outflows at funds holding that security. The pecking order of liquidations would suggest a higher sensitivity for more liquid securities. Specifically, we regress liquidations of bond i by fund j on the outflows at fund j for corporate bonds of different ratings. Liquidations and outflows are measured as their respective percentage changes from the end of February to the end of March but note that the former is at the fund-bond level and the latter is at the fund-level. Controlling for fund and bond level characteristics including maturity, lag fund size, and fund returns, we plot the coefficients on the main explanatory variable, fund outflows, in Figure 10. There is a clearly increasing trend of the plotted liquidation to outflow sensitivities as we go up in corporate bond ratings, implying that more highly-rated bonds are liquidated by more with fund outflows across the ratings spectrum. This trend confirms the pecking order of liquidations.

Figure 10 also illustrates that reverse flight to liquidity does not only speak to holdings of cash. Instead, it is a continuous phenomenon whereby as fundamentals deteriorate, relatively more liquid tranches of the portfolio are sold before less liquid tranches. By the same token, as fundamentals deteriorate, more liquid tranches of the portfolio experience heightened selling pressure and drops in liquidation value before relatively less liquid tranches. During the Covid-19 pandemic, mutual funds' concentrated sale of traditionally liquid assets like Treasuries and highly-rated corporate debt only marks the beginning stages of the general reverse flight to liquidity phenomenon. If fundamentals were to deteriorate further (e.g., if the Federal Reserve did not intervene), investors' redemptions requests would rise and lead to the sale of increasingly illiquid assets from funds' portfolios. In that case, heightened selling pressure and strains may ensue in markets trading more illiquid debt securities.

Another way to shed light on the presence of the pecking order is to compare the behavior of our baseline sample of actively managed mutual funds against that of index funds. Unlike actively managed funds, the portfolio adjustments of index funds are more constrained by the index they are tracking. Thus, the liquidation behavior of active funds should follow the pecking more closely than that of passively managed funds. Figure 11 repeats the specification in Figure 10 with index funds. As seen from the graph, the sensitivity of selling Treasuries is significantly higher while the sensitivity across corporate bonds remains relatively constant. This result confirms that while index funds also hold and use Treasury securities as a liquidity buffer, the pecking order across corporate bonds is constrained by their mandate.

We further compare index funds against actively managed funds to see how the relative liquidity of bonds matters in determining their liquidation to outflow sensitivity. For this purpose, we define the rank of bond i in fund j's portfolio as the share of other bonds held by fund j that are more liquid than bond i. Treasury bills, Treasury notes, and Treasury bonds are of the highest liquidity, which is followed by corporate bonds in decreasing order of their ratings. For example, if a fund holds 20% of Treasury notes, 20% of AAA-rated corporate bonds, and 60% of other corporate bonds with lower ratings, the rank for each of the Treasury notes would be 0.1 and the rank for each of the AAA-rated corporate bonds would be 0.3. Then, we regress the percentage liquidations of each bond i at fund j in March 2020 against fund j's outflows in March 2020 interacted with the rank of bond i as of the end of February. We control for a number of other fund and bond level characteristics detailed in Table 5.

$$\text{Liquidation}_{i,j} = \beta \text{Outflows}_j \times \text{Rank}_{i,j} + \gamma \text{Controls}_{i,j} + \epsilon_{i,j}$$

From the results in Table 5, we see that there are more liquidations of bonds held by funds with larger redemptions. Importantly, this effect is significantly more pronounced for bonds that are high up in the pecking order of liquidations i.e. more liquid bonds. The effect of a bond's relative liquidity is also more important for actively-managed mutual funds relative to passive funds that are constrained by their investment mandate. Taken together, these results indicate that funds indeed chose to follow a pecking order of liquidations to meet redemption requests if they have the option to do so during the Covid-19 crisis.

3.4 Effect on Asset Prices

Finally, we show that asset sales by mutual funds meeting large outflows indeed affected market-level asset prices. Section 2 has shown that mutual funds' outflows and asset sales occur around the same time as Treasury swap spreads and CDS-bond basis of investment-grade bonds widened. To further isolate the price impact induced by mutual funds' selling pressure, we look at how bond-level returns vary with the average outflow at funds who held the security in their portfolio as of 2019Q4. Returns and flows are calculated daily from Jan 1, 2020 to March 31, 2020. We include bond and issuer-time fixed effects to prevent bond characteristics and time-varying issuer characteristics from affecting our findings.

$$\text{Return}_{i,t} = \beta \text{Imputed Outflow}_{i,t} + \gamma \text{Controls}_{i,t} + \epsilon_{i,t}$$

From the results in Table 6, we see that Treasury notes, Treasury bonds and investment-grade corporate bonds that were held by funds suffering larger outflows also experienced larger drops in returns than other securities issued by the same institution. The lack of price impact for high-yield bonds is consistent with funds first selling their more liquid assets to meet redemption requests. During the later half of March, the Federal Reserve also intervened to curb outflows before funds depleted their more liquid asset holdings. Otherwise, if outflows continued to increase, we would expect an effect of fund outflows on high-yield securities as well. The lack of economic and statistical significance for the coefficient on Treasury bills, which are more liquid than Treasury notes and bonds, is also worth noticing. One reason is that funds predominantly hold non-bills because the opportunity cost of return forgone is higher for Treasury bills. At the same time, the intermediation in Treasury bill markets was likely more efficient so that selling pressure by mutual funds induced more limited price impact.

If the results in Table 6 are explained by funds' pecking order of liquidations, we should also expect that returns of bonds higher up in the pecking order at the fund-level experience a larger drop in returns than bonds lower in the pecking order at the same fund. We examine this question by regressing daily returns of bond i on the interaction effect between outflows at fund

j holding bond i at the end of February 2020 and an indicator variable if bond i exceeds the median rank in fund j's portfolio. The rank is defined as before as the share of other bonds in fund j's portfolio that are less liquid than bond i.

$$\text{Return}_{i,t} = \beta \text{Outflow}_{j,t} \times \text{HighRank}_{i,j} + \gamma \text{Controls}_i + \epsilon_{i,j,t}$$

The results in Table 7 confirm that when funds suffer higher outflows, it is only their more liquid bonds that suffer from a drop in returns. Across different specification with a range of controls and fixed effects, the most conservative estimate is that when fund outflows increase by 1%, bonds with an above-median liquidity ranking experience a 3.4 bps larger drop in returns than bonds at the same fund with a below-median liquidity ranking.

The effect of bonds' position in the pecking order of funds' portfolios and hence their likelihood of being liquidated is also evident in aggregate asset prices. Figure 12 plots the yields of bonds grouped by quartiles of their average liquidity rank in funds' portfolios. The yields are demeaned by rating-date fixed effects to purge out the changes in credit risk. From the figure. we see that for bonds of the same rating, those that are ranked higher in the liquidation order of funds' portfolios have higher yields than those lower in the liquidation order during the height of the Covid-19 crisis, which is consistent with the former being sold off my by funds to meet redemption requests.

4 Effect of Federal Reserve Intervention

Finally, we analyze the effect of Federal Reserve interventions on fund flows and asset prices. In response to Covid-19's disruptions to financial markets and the real economy, the Federal Reserve rolled out a series of policy interventions. Most relevant to our analysis are those concerning the purchase of bonds. On March 15, the intention to buy at least \$500 billion in Treasury securities and \$200 billion in government-guaranteed mortgage-backed securities over "the coming months" was announced. On March 23, the Fed committed to purchasing corporate bonds for the first time in history through the Primary Market Corporate Credit Facility (PMCCF) and the Secondary Market Corporate Credit Facility (SMCCF). The purchases were limited to investment-grade corporate bonds and US exchange-traded funds investing in US investment-grade corporate bonds. These limits were relaxed on April 9, when the cap on both facilities expanded to $850 billion and the coverage was extended to include high-yield bonds that were investment grade as of March 22.

We first evaluate the impact of the various policy announcements on fund-level flows by regressing daily fund outflows on indicator variables for each intervention. To ensure that the coefficients capture an announcement effect, we control for the trajectory of the pandemic using the growth rate of infections, include fund fixed effects to remove fund-level heterogeneities, and absorb time trends using month fixed effects.

$$\text{Outflows}_{j,t} = \beta \text{Fed Intervention}_t + \gamma \text{Controls}_{j,t} + \epsilon_{j,t}$$

From Table 8, we see that the the expansion of the corporate bond purchases on April 9 alleviated outflows at high-yield and investment-grade corporate funds. This is in contrast to the purchase of Treasuries, which did not alleviate the subsequent fund outflows. Quantitatively, the announcement of the corporate bond purchase extension (April 9) reduced daily outflows at investment-grade and high-yield funds by 3.9 and 6.9 basis points. Given our event-window is only one day but fund flows are usually persistent, the policy announcement likely had a much more sustained impact on alleviating outflows as also evident from Figure 6.

Our empirical findings can be rationalized through our model. The Fed's commitment to buy a security corresponds to an improvement in its expected return, where the effect is more pronounced for risky securities exposed to the pandemic such as corporate bonds. Therefore, mutual funds holding corporate bonds experience an improvement in the expected future fundamentals of their risky asset, which encourages investors to stay with the fund (i.e., reduces outflows). On the other hand, expected purchases of Treasury securities cannot change investor's expectations about the realization of future fundamentals of the risky asset, and there is no clear impact on fund flows.

The announcement effects on fund NAVs are generally aligned with the results on fund flows. As before, we control for the trajectory of the pandemic using the growth rate of infections, use fund fixed effects to remove fund-level heterogeneities, and absorb time trends using month fixed effects.

$$\text{NAV}_{j,t} = \beta \text{Fed Intervention}_t + \gamma \text{Controls}_{j,t} + \epsilon_{j,t}$$

From Table 9, we find that the announcement of extending corporate bond purchases on April 9 lead to the largest and most consistent increase in fund NAVs. Quantitatively, it lead to increases in daily NAV growth of 1.6% and 1.6% for investment-grade and high-yield funds, respectively. These increases could be directly through raising the valuation of corporate bonds held in funds' portfolios. At the same time, a reduction in outflows reduces the need to liquidate assets at short notice and alleviates the impact of liquidation discounts on fund NAVs. One evidence in support of the latter channel is provided by government funds, which experienced an increase in NAVs following the corporate bond purchase announcements. This may seem surprising at first because government bond funds do not directly hold corporate bonds. If anything, demand may shift away from them towards fund types directly benefiting from the announced purchases. However, this phenomenon can be rationalized by our model. When the announcement of corporate bond purchases curbs outflows at corporate bond funds, their liquidation of relatively liquid assets like Treasuries is reduced, which reduces the price pressure in these liquid asset markets. As a result, the NAV of government bond funds that invest in Treasuries is also improved.

Taken together, our results imply that central bank interventions in traditionally less liquid asset classes such as corporate bonds may become an effective tool for alleviating strains in traditionally more liquid asset markets as mutual funds take on an increasingly important role in liquidity transformation. During the Covid-19 crisis, central bank support for riskier asset classes such as high-yield corporate bonds was more effective at alleviating strains in traditionally liquid asset markets because they prevented fund outflows and liquidations from the outset. In contrast, the purchase of liquid assets like Treasuries does not have a clear effect on curbing investor redemptions but may reduce the liquidation discount of selling Treasuries in secondary markets. The effectiveness of liquid-asset purchases is therefore limited in the presence of large negative shocks to economic fundamentals that induce pronounced investor outflows.

5 Conclusion

This paper shows that liquidity transformation by bond mutual funds contributes to the volatile and concentrated selling pressure in liquid asset markets during the Covid-19 crisis. Such reverse flight to liquidity by mutual funds is pronounced because of funds' liquidity transformation for which redeemable shares is backed by a portfolio of mostly illiquid assets. In meeting redemption requests, funds optimally deplete their stock of liquid assets first before tapping into more-illiquid ones to minimize expected liquidation discounts. Consequently, heightened selling pressure are concentrated in more liquid asset markets, as witnessed during the Covid-19 crisis. A higher degree of liquidity transformation exacerbates the reverse flight to liquidity phenomenon.

In the long run, if financial intermediation is increasingly performed by non-bank intermediaries like fixed-income mutual funds, liquidity transformation will become more cyclical and traditionally liquid asset markets will experience more pronounced volatility over the business cycle. During downturns in particular, when investors are flocking out of fund shares and into cash, there can be large and concentrated selling pressures in more liquid assets such as Treasuries and high-quality corporate debt.

With the increased reliance on mutual fund liquidity transformation and the potential for future reverse flight to liquidity episodes, central bank interventions in traditionally less liquid and more exposed asset classes such as corporate bonds may become an effective tool for alleviating strains in traditionally more liquid asset markets. Central bank support for more exposed asset classes can alleviate fund outflows and liquidations from the onset, whereas the effectiveness of purchasing liquid assets like Treasuries after they have been sold off by mutual funds varies with trading efficiency in secondary markets. After all, Treasuries are traded over-the-counter and dealers' balance sheet constraints coupled with elevated selling pressures may impose significant strains on trading efficiency.

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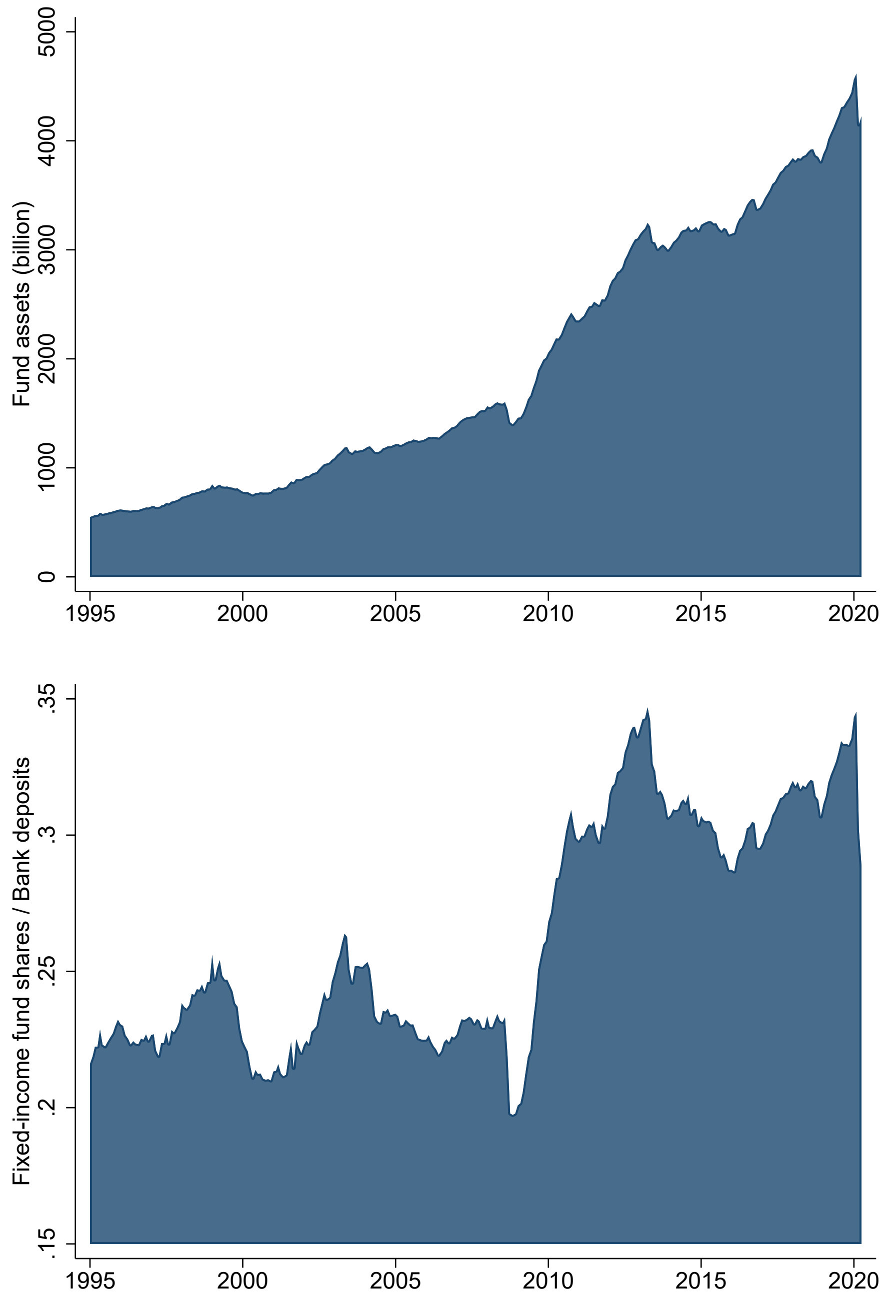

Figure 1: Size of the US Fixed-Income Mutual Fund Sector

The upper panel plots the total asset size of the US fixed-income mutual funds from 1995 to 2019. The lower panel plots ratios of fund shares over bank deposits in the same sample period. Data source: Morningstar and Flow of Funds.

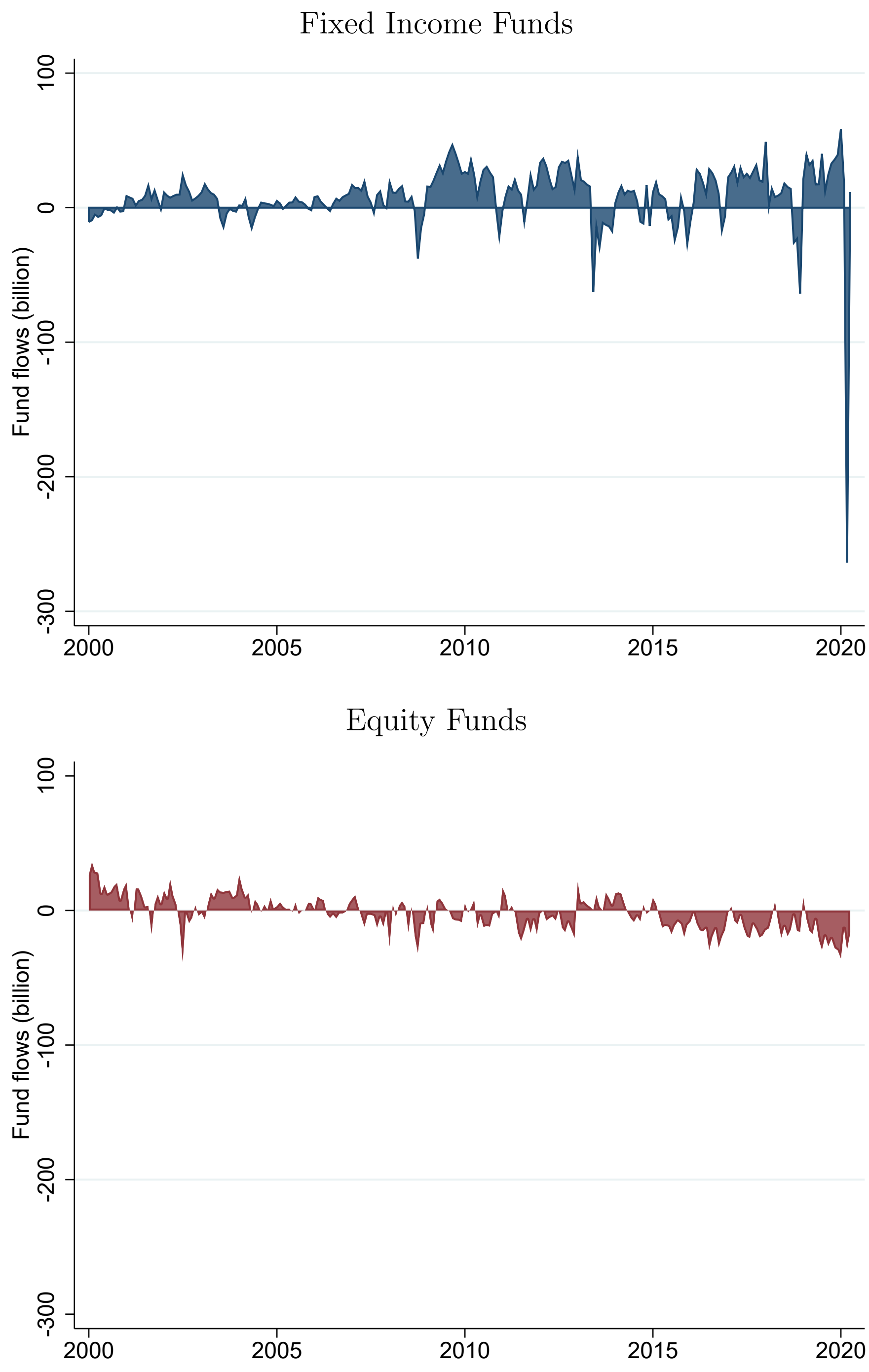

Figure 2: Fund Flows to US Fixed-Income and Equity Funds
The upper plots monthly fund flows to US fixed-income mutual funds from 2000 to 2020. The lower plots monthly fund flows to US equity mutual funds from 2000 to 2020. Data source: Morningstar.

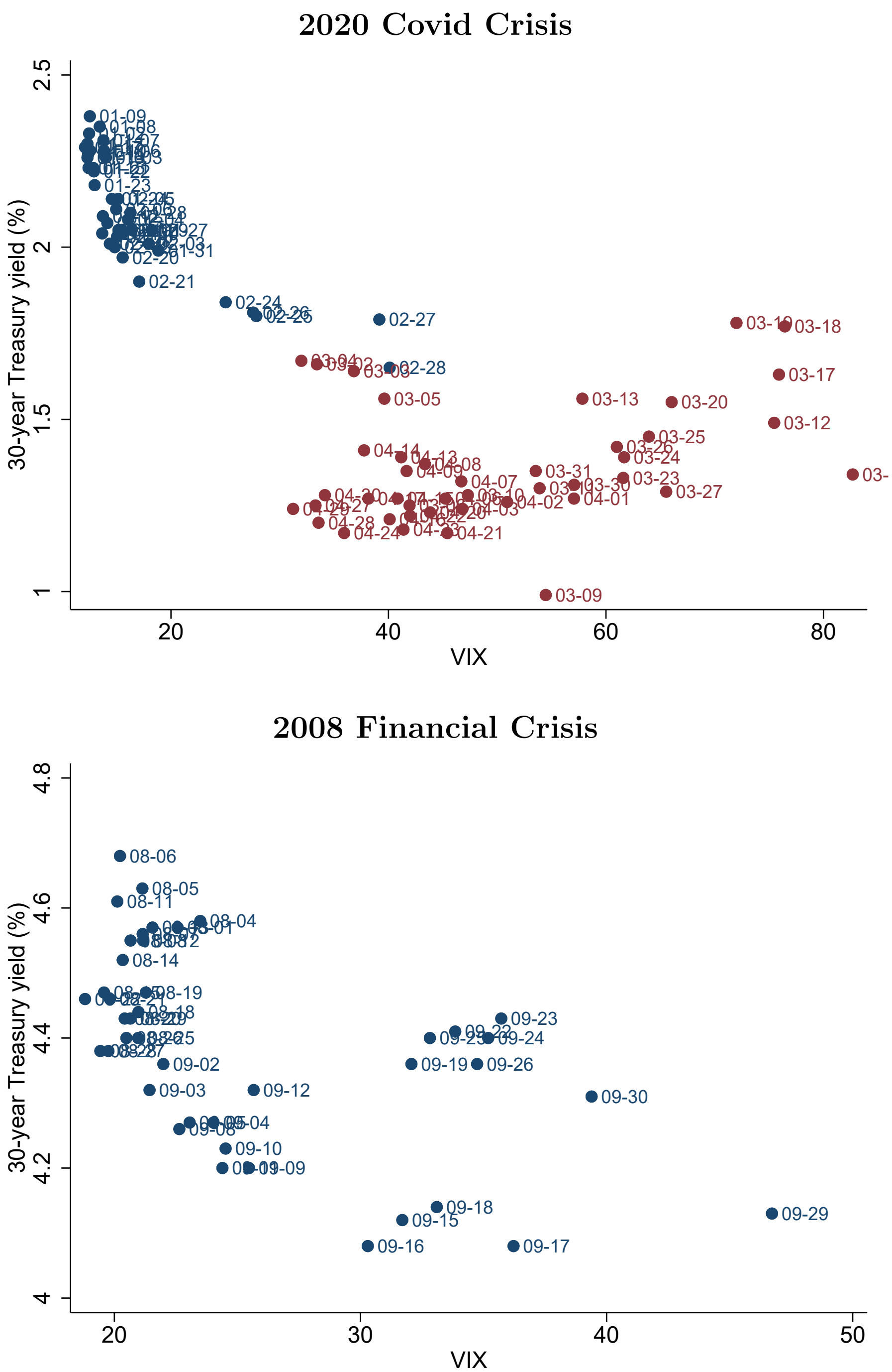

Figure 3: Relationship between Treasury Yield and VIX

This figure shows the scatter plots of 30-year US Treasury yields against the VIX. The upper panel shows the variation during the Covid-19 crisis with blue dots for days in January and February of 2020 and red dots for days in March and April of 2020. The lower panel shows the variation during the 2008 financial crisis from August 1, 2008 to September 30, 2008. Data source: FRED.

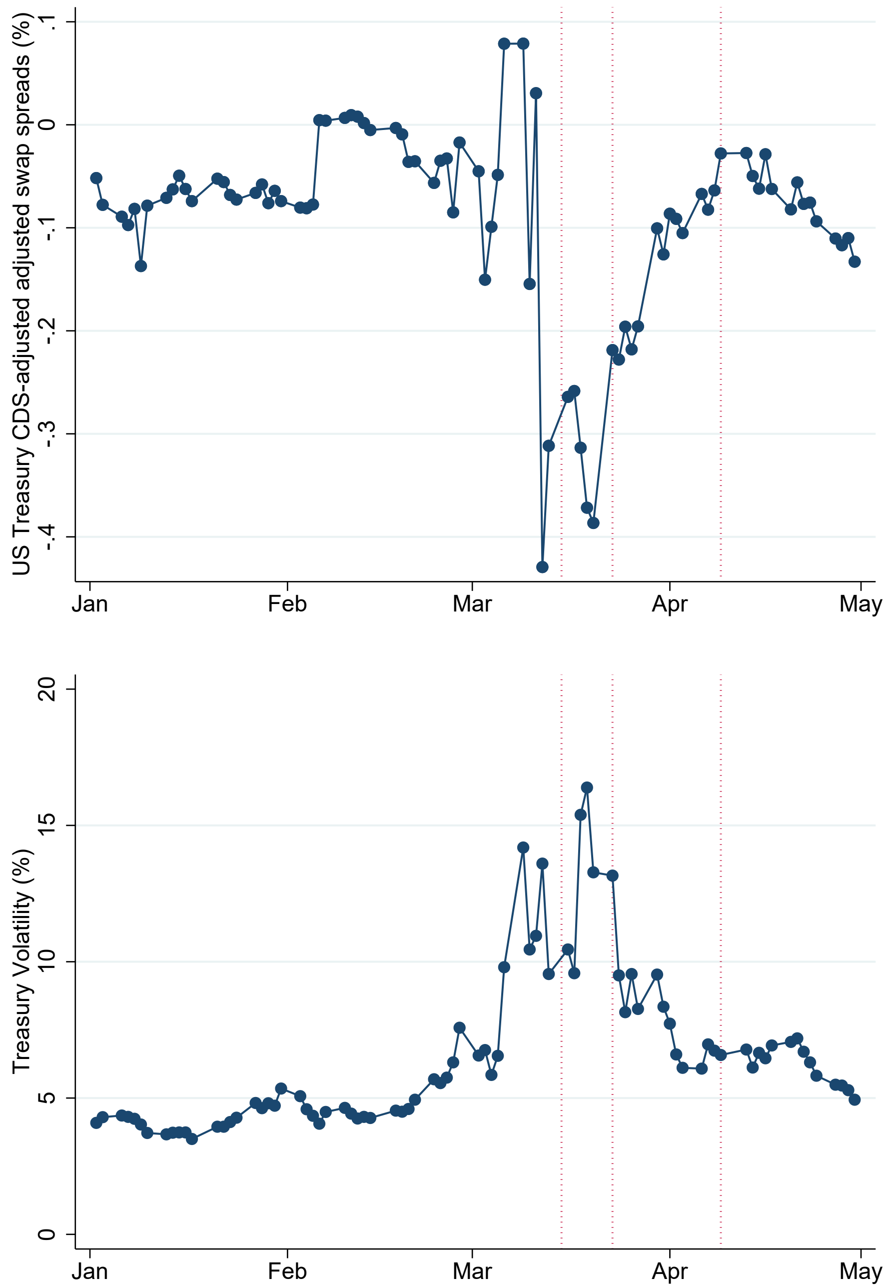

Figure 4: Treasury CDS-adjusted Swap Spreads and Volatility during Covid-19
The upper panel plots the 30-year US Treasury CDS-adjusted adjusted swap spreads, defined as interest swap rate minus Treasury yield plus US sovereign CDS rate with the same maturity. The lower panel plots the CBOE 10-Year Treasury Note Volatility over the same sample period. The sample period is January 1, 2020 to April 30, 2020. Data source: Bloomberg, FRED.

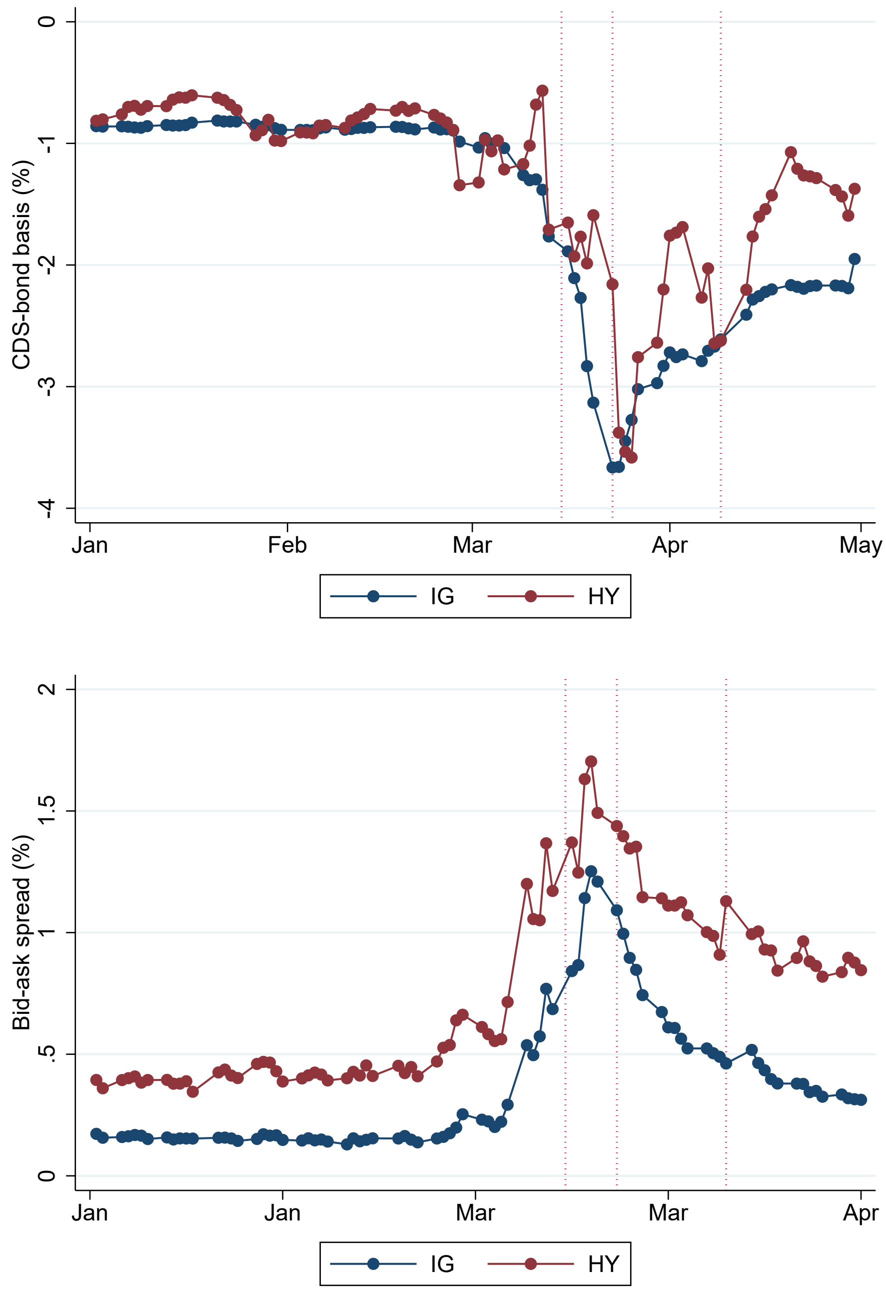

Figure 5: CDS-Bond Basis and Bid-Ask Spreads of US Corporate Bonds
The upper panel plots the US corporate bond CDS basis, defined as the difference between the CDS rate and the bond yield spread. The lower panel plots the bid-ask spreads. The solid and dashed line indicate investment-grade and high-yield bonds, respectively. Data source: Bloomberg, FRED, TRACE.

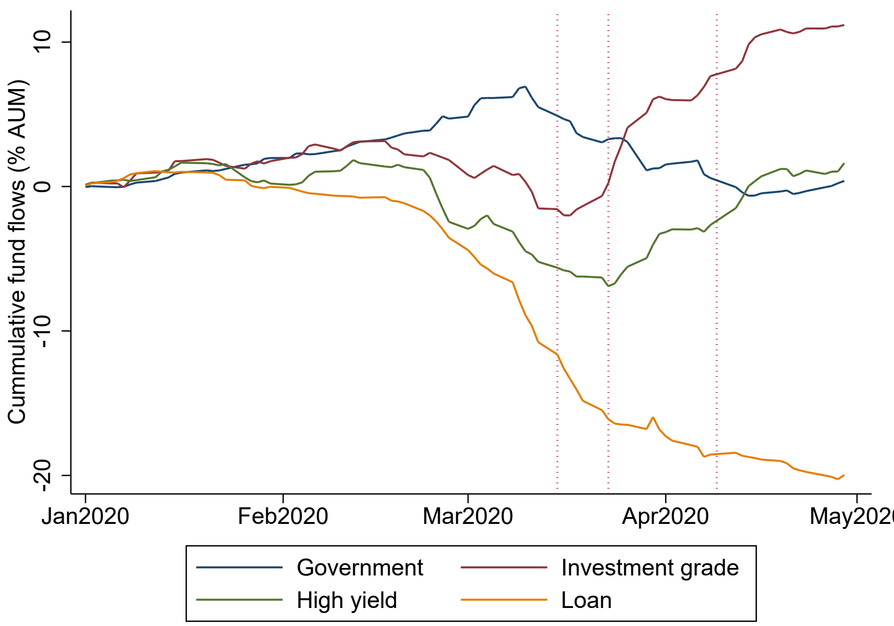

Figure 6: Cumulative Fund Flows of US Fixed-Income Funds by Fund Type
This graph plots asset-weighted cumulative fund flows for US fixed-income funds. The sample period is from January 1, 2020 to April 30, 2020. Data source: Morningstar.

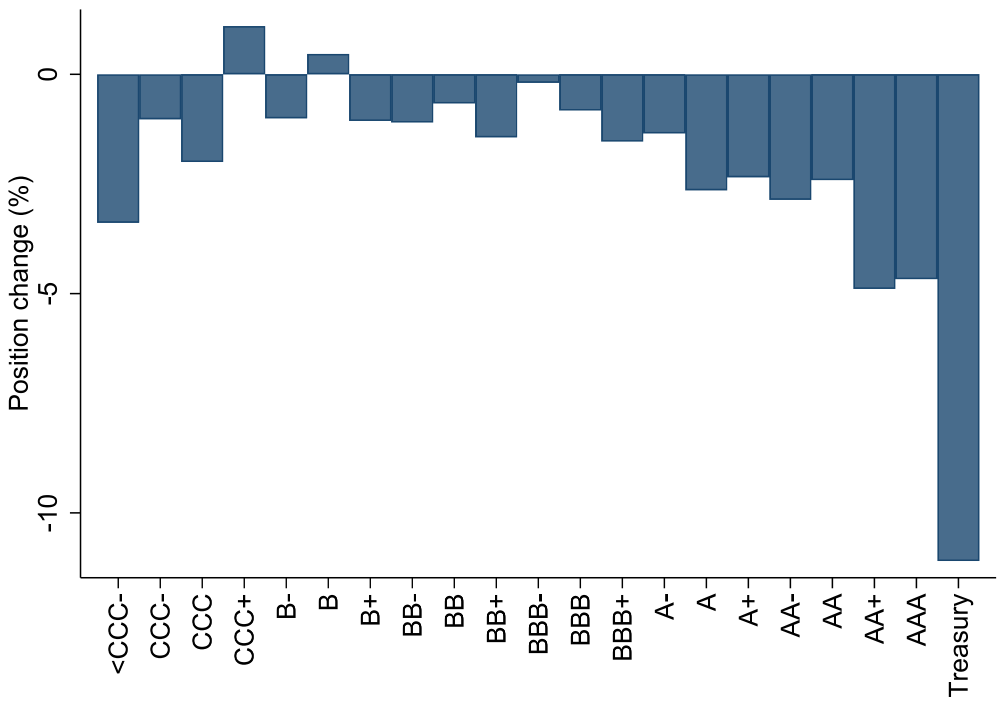

Figure 7: Liquidation by Bond Type in March 2020

This graph plots liquidation as a percentage of holdings at the end of February 2020 by bond type for US fixed-income funds in March 2020. Data source: CRSP.

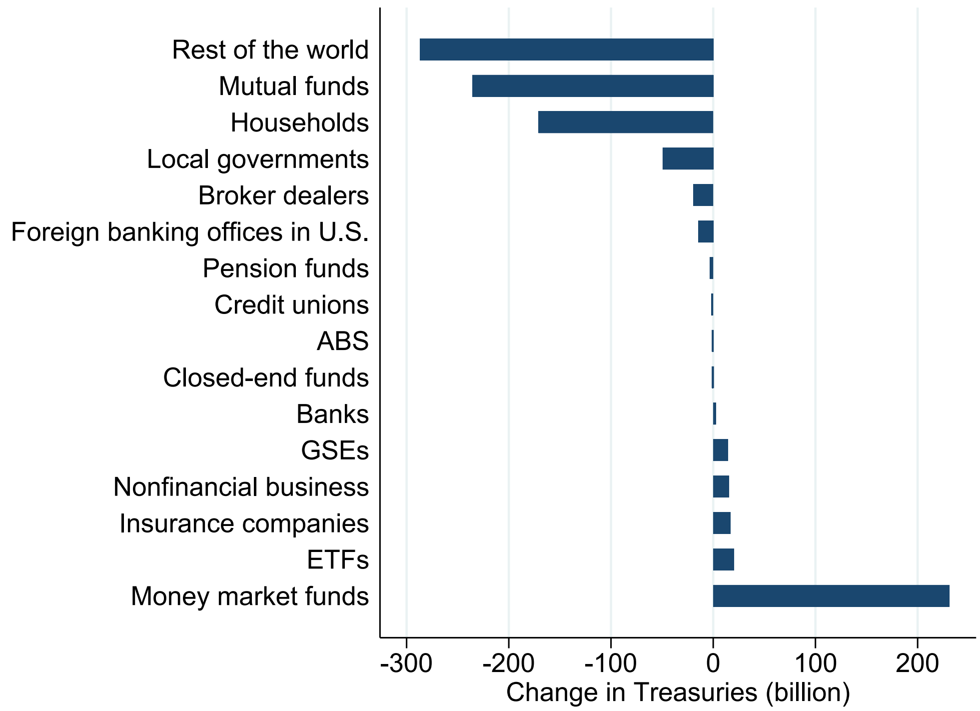

Figure 8: Changes in Treasuries Holding in 2020Q1

This graph plots aggregate position change of Treasury holding for different sectors in 2020Q1. Data source: Flow of Funds.

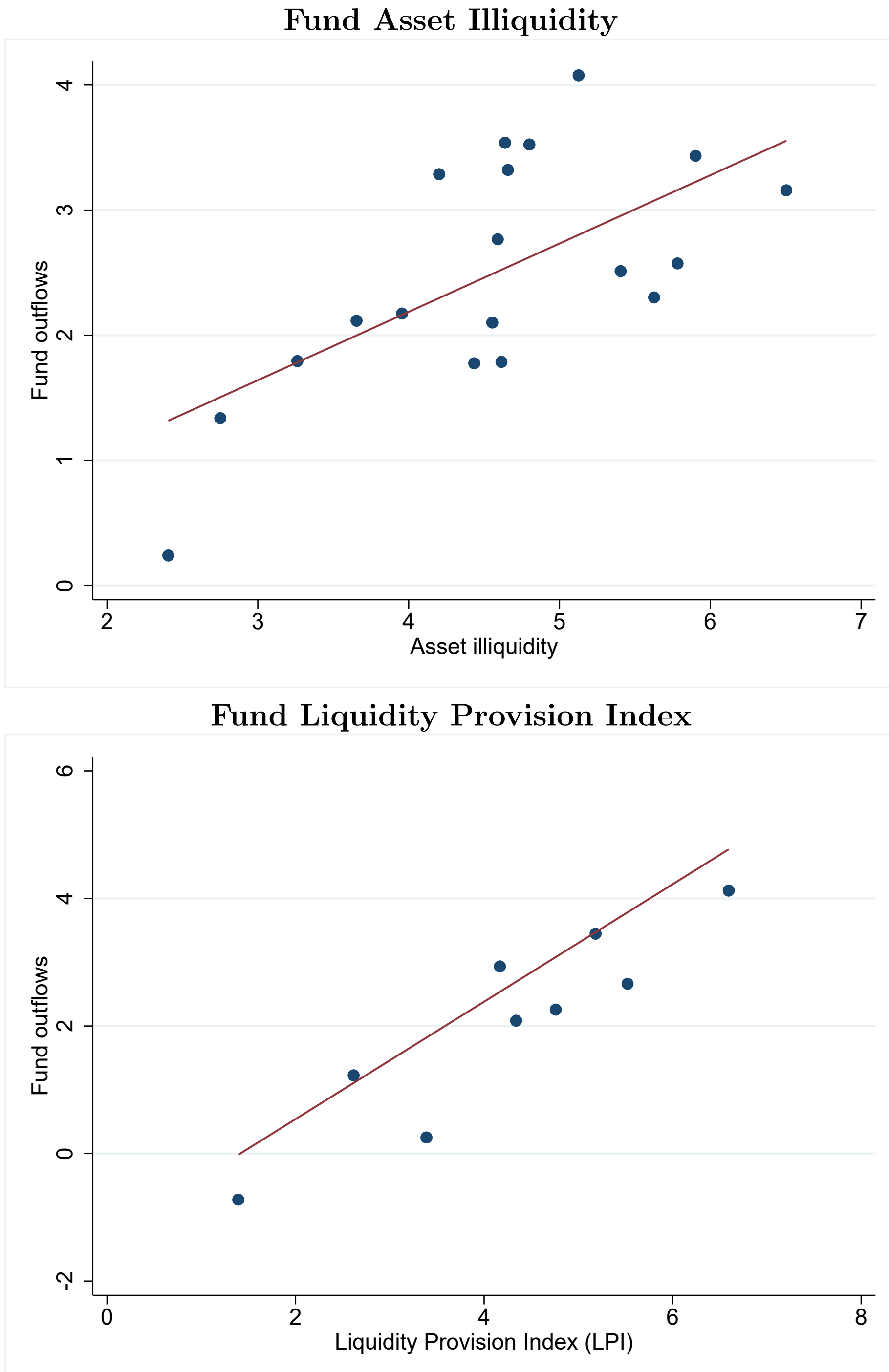

Figure 9: Fund Illiquidity, Liquidity Provision, and Cumulative Fund Outflows
The upper panel is a binned-scatter plot of cumulative fund outflows in March 2020 against funds' asset illiquidity by the end of 2019. The lower panel is a binned-scatter plot of fund outflows in March 2020 against funds' Liquidity Provision Index (LPI) by the end of 2019. The sample includes all U.S. open-end fixed-income mutual funds. Data Source: CRSP.

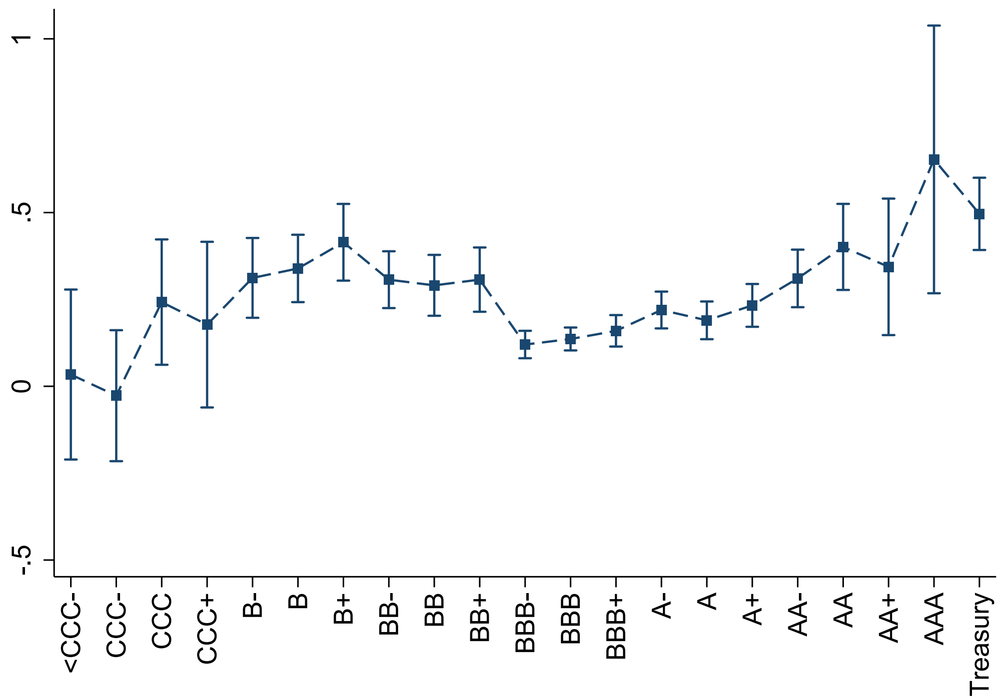

Figure 10: Liquidation-Outflow Sensitivity (Active Funds)

This graph plots coefficients of cross-sectional regressions of each fund's liquidations of individual security positions in March 2020 on the outflows at the same fund for the same period. The sample includes actively-managed open-end funds. The dependent variable *Liquidation* is the change in security holding normalized by the holding at the end of February. The main explanatory variable *outflows* is the amount of outflows normalized by total assets under management at the end of February at funds that held the given security. Control variables for each regression include bond maturity, log fund size, and fund returns. Data source: CRSP.

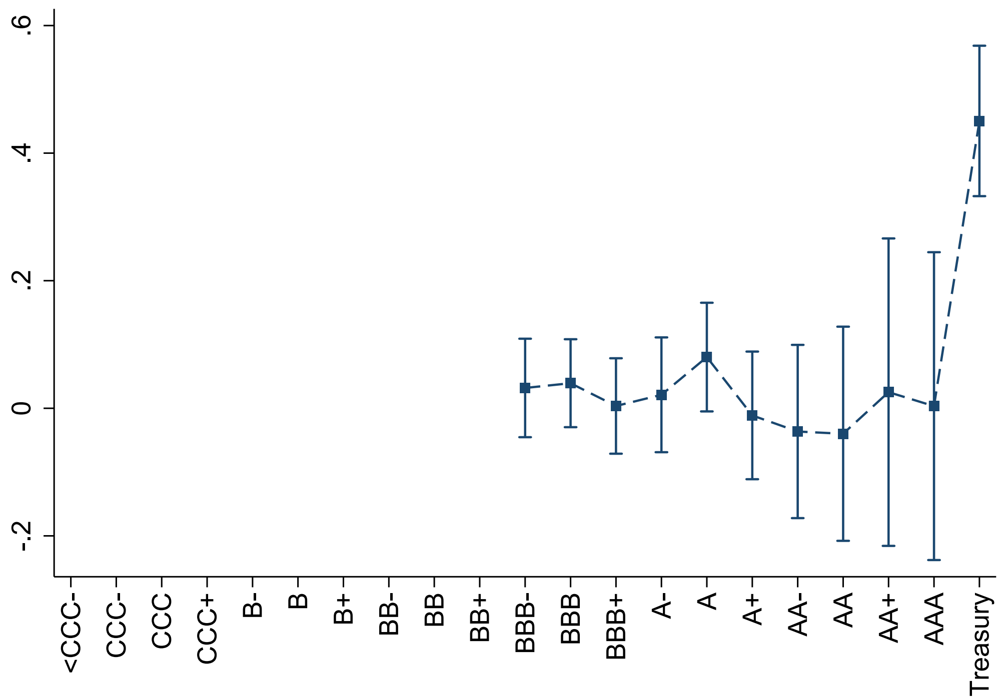

Figure 11: Liquidation-Outflow Sensitivity (Index Funds)

This graph plots coefficients of cross-sectional regressions of each fund's liquidations of individual security positions in March 2020 on the outflows at the same fund for the same period. The sample includes open-end index funds. The dependent variable *Liquidation* is the change in security holding normalized by the holding at the end of February. The main explanatory variable *outflows* is the amount of outflows normalized by total assets under management at the end of February at funds that held the given security. Control variables for each regression include bond maturity, log fund size, and fund returns. Data source: CRSP.

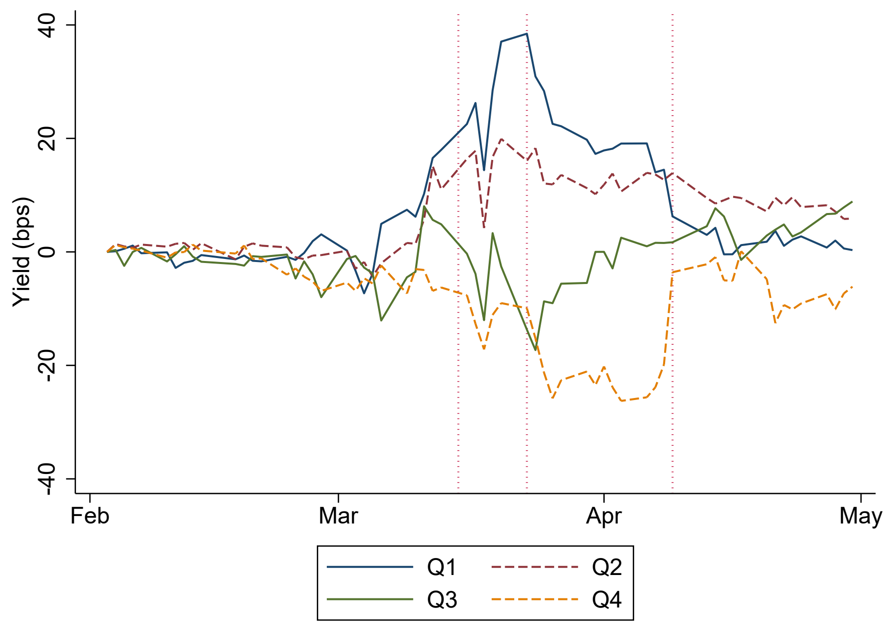

Figure 12: Bond Yields and Pecking Order

This graph plots bond yields by quantiles of their average liquidity rank in fixed-income mutual funds' portfolios. The liquidity rank for a given bond held by a given fund is the proportion of the funds' other holdings that are less liquid than the bond in question. Yields are demeaned by rating-date fixed effects. Data source: TRACE, Mergent FISD, CRSP.

Table 1: Stock and Flow of Treasuries by Sector

	Flow	Level
U.S. Treasury	-542.08	-19018.69
Rest of the world	-287.05	6690.81
Mutual funds	-235.69	1310.90
Households	-170.89	2080.83
Local governments	-49.53	740.28
Broker dealers	-19.47	229.51
Foreign banking offices in U.S.	-14.69	121.08
Pension funds	-3.12	671.48
Credit unions	-1.92	37.54
ABS	-1.01	33.03
Closed-end funds	-0.76	3.17
Banks	2.55	704.08
GSEs	14.37	171.29
Nonfinancial business	15.60	127.12
Insurance companies	17.01	368.70
ETFs	20.46	231.76
Money market funds	231.25	1036.54
Federal Reserve	1019.47	2540.73
Total	-0.31	-106.66
N	18	

This table presents the sector-level stock of Treasuries as of 2019Q4 and the sector-level flow of Treasuries in 2020Q1. The statistics include all the Treasury securities. Breakdowns of Treasury bill and bonds are available for a subset of sectors. The aggregate flows of Treasury bills are \$5 billion, \$195 billion, \$15 billion, \$13 billion, and -\$241 billion, and \$156 for mutual funds, MMFs, insurance companies, rest of the world, the Federal Reserve, and the U.S. Treasury, respectively. Data source: Flow of Funds.

Table 2: Summary Statistics

	mean	sd	p10	p25	p50	p75	p90
Outflows	2.551	8.089	-8.088	-0.754	2.377	6.183	12.760
Fund illiquidity	4.667	1.098	3.040	4.082	4.628	5.515	5.982
Liquidity Provision Index (LPI)	4.184	1.010	3.143	4.184	4.184	4.184	5.354
Volatility	0.727	0.560	0.000	0.350	0.708	0.929	1.377
Return	-5.801	4.881	-12.819	-9.257	-4.580	-2.535	-0.547
Yield	0.475	0.723	0.171	0.203	0.262	0.435	0.727
Maturity	11.424	5.597	5.187	6.760	10.924	14.923	19.022
Expense ratio	0.848	0.282	0.517	0.717	0.848	1.005	1.137
Turnover ratio	0.993	1.320	0.150	0.290	0.600	0.993	2.030
Cash	-0.695	10.808	-8.530	-0.490	0.740	2.220	4.700
Government	20.496	27.522	0.000	0.000	6.160	32.570	68.180
Corporate bonds	29.590	31.379	0.000	0.000	23.700	46.690	85.770
ABS	7.433	12.439	0.000	0.000	0.090	11.320	24.000
MBS	8.349	13.995	0.000	0.000	0.000	12.110	29.990
Other debt	5.299	16.302	0.000	0.000	0.635	2.640	8.300
Maturity	11.424	5.597	5.187	6.760	10.924	14.923	19.022

This table presents the summary statistics of portfolio holding of US fixed-income mutual funds in March 2020. The portfolio weights are in percentages of total assets. Data source: CRSP.

Table 3: Fund Asset Illiquidity and Fund Outflows

	(1) Outflow	(2) Outflow	(3) Outflow	(4) Outflow
Fund illiquidity	0.546***	0.545***	0.537***	0.564***
	[0.092]	[0.092]	[0.094]	[0.096]
Institutional		0.137	0.135	0.283
		[0.203]	[0.203]	[0.204]
Index fund			-0.259	-0.614
			[0.595]	[0.602]
Volatility				1.600***
				[0.192]
Yield				-0.179
				[0.141]
Expense ratio				-0.724*
				[0.384]
Turnover ratio				-0.474***
				[0.077]
Investment objective F.E.	No	No	No	Yes
Observations	6,355	6,355	6,355	6,355
Adj. R-squared	0.005	0.005	0.005	0.021

This table presents cross-sectional regressions of outflows in March 2020 on fund characteristics measured by the end of 2019. "Fund illiquidity' is the weighted average of fund asset illiquidity proxied by haircuts. "Volatility" is the standard deviation of monthly return over the past five years. "Return" is the monthly return. "Yield" is the average income yield of the fund portfolio holdings. Fund character characteristics are measured at the end of 2019. The sample includes all U.S. fixed-income open-end mutual funds. Data source: CRSP.

Table 4: Fund Liquidity Transformation and Fund Outflows

	(1) Outflow	(2) Outflow	(3) Outflow	(4) Outflow
Liquidity Provision Index (LPI)	0.921***	0.921***	0.915***	0.816***
	[0.100]	[0.100]	[0.101]	[0.103]
Institutional		0.159	0.156	0.282
		[0.202]	[0.202]	[0.204]
Index fund			-0.274	-0.698
			[0.586]	[0.596]
Volatility				1.463***
				[0.190]
Yield				-0.197
				[0.141]
Expense ratio				-0.648*
				[0.382]
Turnover ratio				-0.407***
				[0.078]
Investment objective F.E.	No	No	No	Yes
Observations	6,355	6,355	6,355	6,355
Adj. R-squared	0.013	0.013	0.013	0.026

This table presents cross-sectional regressions of outflows in March 2020 on fund characteristics measured by the end of 2019. "LPI" is the liquidity provision index introduced by Ma, Xiao and Zeng (2019). "Volatility" is the standard deviation of monthly return over the past five years. "Return" is the monthly return. "Yield" is the average income yield of the fund portfolio holdings. Fund character characteristics are measured at the end of 2019. The sample includes all U.S. fixed-income open-end mutual funds. Data source: CRSP.

Table 5: Pecking Order and Liquidation-Outflow Sensitivity

	(1) All	(2) Active	(3) Index
Outflows	0.230***	0.199***	0.153***
	[0.014]	[0.021]	[0.028]
Outflows*Rank	0.251***	0.397***	0.234*
	[0.040]	[0.049]	[0.122]
Maturity	0.024***	-0.021**	0.049***
	[0.005]	[0.008]	[0.007]
Coupon rate	-0.076**	-0.087*	-0.128***
	[0.035]	[0.050]	[0.047]
Rating F.E.	Yes	Yes	Yes
Fund objective F.E.	Yes	Yes	Yes
Observations	80,332	40,460	39,871
Adj. R-squared	0.021	0.027	0.018

This table presents a cross-sectional regression of liquidations of a given security by a fund on the outflows of the fund in March 2020. Outflows and liquidations are expressed as percentage changes in March 2020. Rank is measured by the relative liquidity rank of the security in the fund's portfolio. Security holdings and liquidity rank are measured at the end of February 2020. Data source: CRSP and TRACE.

Table 6: Effect of Fund Outflows on Bond Returns

	(1) T-bill	(2) T-note	(3) T-bond	(4) Corp IG	(5) Corp HY
Outflows	0.094	-0.446**	-4.969**	-4.733***	-3.145
	[0.097]	[0.204]	[2.441]	[1.198]	[2.194]
Bond F.E.	Yes	Yes	Yes	Yes	Yes
Rating-Time F.E.	Yes	Yes	Yes	Yes	Yes
Maturity-Time F.E.	Yes	Yes	Yes	Yes	Yes
Observations	1,069	10,464	113,521	316,078	67,900
Adj. R-squared	0.140	0.959	0.213	0.166	0.160

This table presents a panel regression of daily security-level returns on the average outflows at funds holding the security. Security holdings are based on 2019Q4 and the sample period is from Jan 1, 2020 to March 31, 2020. Bond returns are expressed in basis points. Imputed outflows are expressed in percentage points. The standard errors in brackets are clustered at the security level. Data source: CRSP and TRACE.

Table 7: Fund Flows on Bond Returns

	(1) Return	(2) Return	(3) Return
Outflows	-1.646	-1.741	-1.856
	[1.167]	[1.174]	[1.194]
Outflows*High rank	-3.443**	-3.550**	-3.506**
	[1.426]	[1.433]	[1.459]
Rating-Time F.E.	Yes	No	No
Maturity-Time F.E.	Yes	No	No
Issuer F.E.	No	Yes	Yes
Bond F.E.	No	No	Yes
Observations	398,678	398,678	398,677
Adj. R-squared	0.174	0.175	0.166

This table presents a panel regression of daily security-level returns on the average outflows at funds holding the security. Security holdings are based on 2019Q4 and the sample period is from Jan 1, 2020 to March 31, 2020. Bond returns are expressed in basis points. Outflows are expressed in percentage points. Rank is measured by the relative liquidity rank of the security in the fund's portfolio and high rank indicated an above-median rank. The standard errors in brackets are clustered at the security level. Data source: CRSP and TRACE.

Table 8: Federal Reserve Announcement Effects on Fund Outflows

	(1) Govt	(2) IG	(3) HY	(4) BL
Treasury bond purchase	0.014	0.043	0.093***	0.093***
	[0.032]	[0.039]	[0.026]	[0.033]
Corp bond purchase	0.217***	0.366***	-0.057	0.161***
	[0.040]	[0.063]	[0.035]	[0.051]
Corp bond purchase expansion	0.057***	-0.039**	-0.069***	-0.073***
	[0.017]	[0.019]	[0.008]	[0.010]
Control	Yes	Yes	Yes	Yes
Fund fixed effects	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes
Observations	13,573	6,452	17,819	9,364
Adj. R-squared	0.058	0.071	0.067	0.096

This table presents panel regressions of daily fund outflows (in %) on announcements of Federal Reserve interventions. "Treasury bond purchase" refers to the announcement of buying at least $500 billion in Treasury securities and $200 billion in government-guaranteed mortgage-backed securities on March 15; "Corp bond purchase" to the March 23 announcement of the Primary Market Corporate Credit Facility (PMCCF) and the Secondary Market Corporate Credit Facility (SMCCF); and "Corp bond purchase expansion" refers to the April 9 announcement on raising the cap to $850 billion and the inclusion of high-yield bonds that were investment grade as of March 22. The event window is one day. The sample period is from January 1, 2020 to April 30, 2020. Columns (1) to (4) correspond to outflows of government, investment-grade, high-yield, and bank loan funds, respectively. The standard errors in brackets are clustered at the fund-level. Data source: Morningstar.

Table 9: Federal Reserve Announcement Effects on Fund NAVs

	(1) Govt	(2) IG	(3) HY	(4) BL
Treasury bond purchase	0.241**	0.188	-2.336***	-2.618***
	[0.119]	[0.236]	[0.274]	[0.290]
Corp bond purchase	0.901***	0.866**	-1.261**	-1.941***
	[0.178]	[0.400]	[0.486]	[0.487]
Corp bond purchase expansion	0.399***	1.616***	1.621***	1.114***
	[0.039]	[0.066]	[0.111]	[0.095]
Control	Yes	Yes	Yes	Yes
Fund fixed effects	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes
Observations	13,565	6,451	17,816	9,357
Adj. R-squared	0.180	0.427	0.323	0.377

This table presents panel regressions of daily percentage changes in fund NAVs on announcements of Federal Reserve interventions. "Treasury bond purchase" refers to the announcement of buying at least $500 billion in Treasury securities and $200 billion in government-guaranteed mortgage-backed securities on March 15; "Corp bond purchase" to the March 23 announcement of the Primary Market Corporate Credit Facility (PMCCF) and the Secondary Market Corporate Credit Facility (SMCCF); and "Corp bond purchase expansion" refers to the April 9 announcement on raising the cap to $850 billion and the inclusion of high-yield bonds that were investment grade as of March 22. The event window is one day. The sample period is from January 1, 2020 to April 30, 2020. Columns (1) to (4) correspond to NAVs of government, investment-grade, high-yield, and bank loan funds, respectively. The standard errors in brackets are clustered at the fund-level. Data source: Morningstar.

A Model

Although the main contribution of this paper is empirical, we build a simple model of mutual funds in the spirit of Diamond and Dybvig (1983) to guide the empirical analysis. Using the Diamond-Dybvig framework (as opposed to other workhorse models of mutual fund flows) is important because it allows us to highlight the nature of the underlying assets being illiquid and to uncover the consequences of liquidity transformation by mutual funds. For the same reason, we abstract away from mutual fund skills and any agency frictions which are not directly related in our context.

A.1 Setting

The economy has three dates, $t = 0, 1, 2$, with no time discount. There is a $[0, 1]$ continuum of ex-ante identical households, each of which has one unit of the consumption good at $t = 0$, which is the numeraire, and no endowment afterward. Each household is uncertain about her preferences over consumption at $t = 1$ and $t = 2$. At the beginning of $t = 1$, a household learns her preferences privately: with probability π she is an early-type and gets utility $u(c_1)$ from date-1 consumption only, while with probability $1 - \pi$ she is a late-type and gets utility $u(c_2)$ from date-2 consumption only. There are two long-term assets available for portfolio choice at $t = 0$: a relatively more illiquid asset called "project", denoted by y, and a relatively less illiquid asset called "Treasury", denoted by x. There is also a private savings technology available at $t = 1$ to transfer wealth to $t = 2$.

The project is risky. One unit investment in the project at $t = 0$ yields R units of goods at $t = 2$, where R is a random variable that follows a distribution of $G(\cdot)$ with support $[0, +\infty)$. Denote R as the fundamentals of the economy; since R is uncertain, the economy entails aggregate risks. In contrast, the Treasury is riskless; one unit investment in the Treasury at $t = 0$ yields 1 unit of good at $t = 2$ as a normalization. We also assume that $E[R] = 1$ as a normalization.

There are two dimensions of illiquidity at the asset-level. First, at $t = 1$, the project has not yet attained its long-term return and has a normalized value of 1. This can be thought of as long-term productive projects taking time to come to fruition, and its value at $t = 1$ cannot reflect its value at $t = 2$. Second, if either the project or the Treasury are prematurely liquidated at $t = 1$, a liquidation discount is incurred that results in a lower marginal liquidation value in the spirit of Shleifer and Vishny (1992). Specifically, for each asset $j \in \{x, y\}$, when amount l_j is prematurely liquidated at $t = 1$, a total liquidation cost of $\phi_j l_j$ is incurred, meaning that the amount of consumption good raised from this liquidation is only $(1 - \phi_j)l_j$. In reality, those two dimensions of illiquidity jointly reflect the features of illiquid asset prices not being fully forward-looking but only updated when actually trading or liquidation happens (e.g., Duffie, 2010). We assume that the project is more illiquid and suffers higher liquidation discounts than the Treasury: $0 \leq \phi_x < \phi_y < 1$. When $\phi_x = 0$, the Treasury can be interpreted as cash which does not entail any liquidation cost.

The private savings technology, which is available at $t = 1$, is riskless but inefficient in that a unit investment only yields γ units of goods from $t = 1$ to $t = 2$. Specifically, we assume $\gamma = 1 - \kappa n$, where $\kappa > 0$ captures the decreasing returns to scale and n is the population of late households that use this savings technology. The decreasing returns to scale of the savings technology can be thought of as returns on short-term alternative investments decreasing with increased demand.

The order of play is as follows. At $t = 0$, all households pool their endowments to collectively form a representative mutual fund, which then allocates the pool of endowments into the two assets. We will henceforth denote the underlying economy as a fund economy. At the beginning of $t = 1$, every household i receives a private signal of R: $s_i = \theta(R) + \varepsilon_i$, where $\theta(R) \in [0, 1)$ is strictly increasing in R, and ε_i is i.i.d. and arbitrarily small. We specify the detailed distribution of ε_i below as we solve for the equilibrium. Since this signal is private, it is neither contractable nor available to the mutual fund at $t = 1$. Given the mutual fund contract payments that we specify below, an early household always leaves the fund at $t = 1$ regardless of the signal she receives, while a late household chooses whether to leave the fund depending on her signal. The better the signal R, the higher the incentive for late households to stay with the fund, wait for the project to come to fruition, and to benefit from the long-run return. We denote by λ the total amount of households who leave the intermediary at $t = 1$. Finally at $t = 2$, fundamentals R are realized and the remaining proceedings are paid out.

Specifically, the representative open-end mutual fund makes portfolio choices (x, y) at $t = 0$ on households' behalf, where x is the amount of Treasury and y the amount of projects. Since the mutual fund is representative, it maximizes households' utility and breaks even in equilibrium.

The representative open-end mutual fund also offers an NAV-based equity contract $(c_1(\lambda), c_2(\lambda))$ in which the cash payments are the end-of-date net asset values (NAVs). When NAVs are fully flexible, any potential liquidation costs incurred at $t = 1$ are fully incorporated into NAV_1 so that liquidation costs are proportionally borne by redeeming and non-redeeming households. In line with reality, we also consider imperfectly flexible NAVs, where liquidation costs are only partially incorporated into NAV_1. In other words, fund NAVs may be stale. To this end, we introduce a parameter $\mu \in [0, 1]$ to capture the stickiness of fund NAVs. Given liquidations l_x and l_y at $t = 1$, the fund NAV at the end of $t = 1$ is given by

$$NAV_1 = x - (1 - \mu)\phi_x l_x + y - (1 - \mu)\phi_y l_y \,.^5 \tag{A.1}$$

Intuitively, $\mu = 0$ captures the benchmark case in which fund NAVs are fully flexible. As μ increases, more of the incurred liquidation costs will not be reflected in the the end-of-day NAV so that the NAV becomes stale. To simplify the analysis without much loss of generality, we consider a sufficiently small μ throughout the paper to avoid the emergence of multiple equilibria in the fund economy.[6] However, we note that the prediction regarding fund flows still holds even when μ is large and multiple equilibria emerge; we refer interested readers to the model in Chen, Goldstein and Jiang (2010) for an analysis.[7]

Remark 1. We note that illiquid asset values not being forward-looking and fund NAVs not being perfectly flexible are two independent frictions both in our model and in reality. The first friction matters pertaining to the asset market level and constrain asset prices from updating when no liquidation happens, while the second friction matters pertaining to the fund level and constrains the fund's ability to incorporate all the liquidation costs into end-of-day NAVs. Another way to see the difference of those two frictions is that swing pricing, a policy that has been recommended in the US and implemented in Europe to help funds more flexibly adjust

[5]Note that when μ is positive and when the redemption amount λ is large enough, the fund NAV as given by (A.1) may not be sustained even if the fund is fully liquidated, in which case households will get a proportional share of the liquidation value of the underlying portfolio.

[6]To see how multiple equilibria may arise, just notice that in the extreme case of $\mu = 1$, $NAV_1 = 1$ by equation (A.1), which implies the mutual fund essentially becomes a bank offering with a debt contract at $t = 1$. We analyze this case as another benchmark in more detail and explore its asset pricing implications in Appendix A.4.

[7]In more detail, Chen, Goldstein and Jiang (2010) consider a different model of mutual fund flows which effectively resembles our case of $\mu = 1$ but has an additional explicit flow-to-performance relationship as observed in reality. In that model, they use the global games technique to pin down a unique equilibrium and show that the equilibrium threshold is higher when the fund's underlying asset is more illiquid. That result in their framework thus suggests that more illiquid funds are subject to a stronger flow-to-performance relationship.

their NAVs, can fix the second fund-level friction but would not directly fix the first market-level friction. As we theoretically show below, the first friction is important to explain why mutual funds are subject to fundamentals-driven flows at all, while the second friction is important to explain why fund flows are larger when funds become more illiquid and consequently the NAVs are more sticky.

Remark 2. We also note that, in reality, funds that transform more liquidity by specializing in more illiquid projects (i.e., a larger ϕ_y) also tend to be subject to larger NAV stickiness (i.e., a larger μ) at the fund level. One reason is that more illiquid assets are traded less frequently in secondary markets, so their pricing tends to be more stale. Further, funds that specialize in more illiquid assets (e.g., a high-yield bond fund) also tend to derive NAVs using more complex models compared to funds that specialize in more liquid assets (e.g., a large-cap equity fund), which may introduce additional margins of error. Thus, although we designate ϕ_y and μ as two different parameters, they can be viewed as being positively correlated in practice.

Before solving the model and analyzing its asset market implications, we first define the notion of reverse flight to liquidity.

Definition 1. *An economy has the potential for reverse flight to liquidity if there exists a non-zero-measure region Δ such that when $R \in \Delta$, the realized liquidation amount of the Treasury $l_x(R)$ strictly decreases in R and is larger than that of the project, that is, $l_x(R) > l_y(R)$. Actual reverse flight to liquidity happens when the realized R falls in Δ.*

Intuitively, reverse flight to liquidity occurs when upon the arrival of worse news about future fundamentals, the Treasury is sold off, and by more than the less liquid project is. This is in contrast to a typical flight to liquidity scenario in which there is a net pressure to buy more liquid assets in response to signs of deteriorating fundamentals.

It is important to note the separate but intricately related roles of idiosyncratic and aggregate risks in the economy. Mutual fund liquidity transformation provides value to households by helping households to insure against idiosyncratic liquidity risks, which resembles the role of banks in Diamond and Dybvig (1983). In this sense, the presence of idiosyncratic risks in the mutual fund economy justifies why mutual fund liquidity transformation exists in the first place. Given mutual funds' portfolio of liquid and illiquid assets and their issuance of fund shares in liquidity transformation, the presence of aggregate risks in the economy in turn leads to unique implications for asset markets when there are changes in economic fundamentals.

Note also that Definition 1 does not rely on any specific institutional or contractual settings. In other words, reverse flight to liquidity as in Definition 1 may arise in environments other than our mutual fund economy. This is in line with our paper's goal to identify mutual fund liquidity transformation as an important contributor to the general reverse flight to liquidity phenomenon. As we will show, among various types of liquidity-providing financial intermediaries, those that issue demandable equity, such as open-end mutual funds, are more likely to induce reverse flight to liquidity than deposit-funded commercial banks.

A.2 Equilibrium Analysis

We work backwards on the mutual fund's optimal portfolio choice at $t = 0$ and liquidation decision at $t = 1$, taking household decisions into account. First, at $t = 1$, the fund pays out the end-of-day NAV to redeeming households. Since the fund does not have any consumption goods on hand, it has to liquidate either or both the Treasury and the project. Because both assets have the same expected returns but the project is more illiquid than the Treasury (i.e., $\phi_y > \phi_x$), the representative fund will first liquidate the Treasury to meet redemption requests. A pecking order of asset liquidation results, in which mutual funds liquidate less illiquid assets before more illiquid ones.[8]

Before we analyze how fund flows respond to future fundamentals, we first note a straightforward result regarding how idiosyncratic liquidity shocks shape the fund's portfolio choice at $t = 0$ and liquidation decisions at $t = 1$:[9]

Lemma 1. *In any equilibrium the fund's Treasury holdings must satisfy $x^* \geq \pi NAV_1(\pi)$, and the fund always liquidates Treasury first to meet redemptions by the π early households.*

Lemma 1 stems from the fact that π early households always leave at $t = 1$ regardless of the fundamentals. Thus, the fund always holds enough Treasury at $t = 0$ and ends up liquidating those Treasury holdings first at $t = 1$. Otherwise, the fund may increase Treasury holdings $t = 0$

[8] Note that the pecking order of liquidation may not be optimal in a dynamic setting in which negative shocks are persistent. In that setting, a precautionary motive to sell some more illiquid assets first may arise because exhausting all the liquid buffers would make it too hard for the fund to weather future persistent shocks. See Brown, Carlin and Lobo (2010) for a theoretical analysis and Jiang, Li and Wang (2020) for supporting evidence. We believe, however, our static setting with a short-lived shock indeed captures the onset of the Covid-19 crisis due to the expectations of investors ex-ante as well as the extremely fast government interventions ex-post.

[9] The proof follows from a perturbation argument based on the intuition described below and we omit it for simplicity.

to reduce the inefficient liquidation cost of the more illiquid project. Thus, Lemma 1 suggest that idiosyncratic liquidity shocks directly lead to liquidation of the Treasury independent to economic fundamentals. Although this result is not uninteresting and is consistent with a view that the market disruptions in March 2020 may be partly driven by idiosyncratic liquidity needs, we are more interested in fund flows and asset market outcomes driven by economic fundamentals according to Definition 1. For that reason, below we focus on the case of $\pi \to 0$ to highlight the implication of aggregate fundamental shocks on the fund and asset markets.

The following main result gives the relationship between fundamentals R, fund outflows, and asset liquidations:

Proposition 1 (Reverse flight-to-liquidity)**.** *Given any date-0 fund position:*

i). Late households optimally redeem $\lambda^*(R)$, where $\lambda^*(R)$ decreases in R and the closed-form expression of $\lambda^*(R)$ is given by (C.5).

ii). There exists $\widehat{R} < 1$ such that when $\widehat{R} < R < 1$, the fund optimally liquidates $l_x^*(R)$ of the Treasury but none of the project, where $l_x^*(R)$ strictly increases in $\lambda^*(R)$ and thus decreases in R. When $R < \widehat{R}$, the project is liquidated and the liquidation amount $l_y^*(R)$ also increases in $\lambda^*(R)$ and thus decreases in R.

Proposition 1 implies that reverse flight to liquidity induced by fund flows happens in the region $\Delta = (\widehat{R}, 1)$ according to Definition 1. The first part of Proposition 1, illustrated by the upper panel of Figure 13, shows that fund outflows continuously increase as households' prospect about future economic fundamentals worsens. Intuitively, because fundamentals R only fully materializes in the long run and cannot be reflected in the short-term value of the project unless liquidation happens, late households are better off to redeem at $t = 1$ when future fundaments at $t = 2$ are expected to be bad. This motive explains why there are fund flows in the first place. However, when flow-induced liquidation happens, fund NAV at $t = 1$ adjusts flexibly by incorporating the resulting liquidation costs, leading to a continuously lower NAV at $t = 1$. This further justifies why fund flows continuously respond to drops in future fundamentals, that is, there are more outflows when and only when future fundamentals become worse.

The second part of Proposition 1, illustrated by the lower panel of Figure 13, links fund flows to reserve flight to liquidity. Because the fund follows the pecking order of liquidation in meeting redemptions, the more liquid Treasury is sold off before the less liquid project when fundamentals

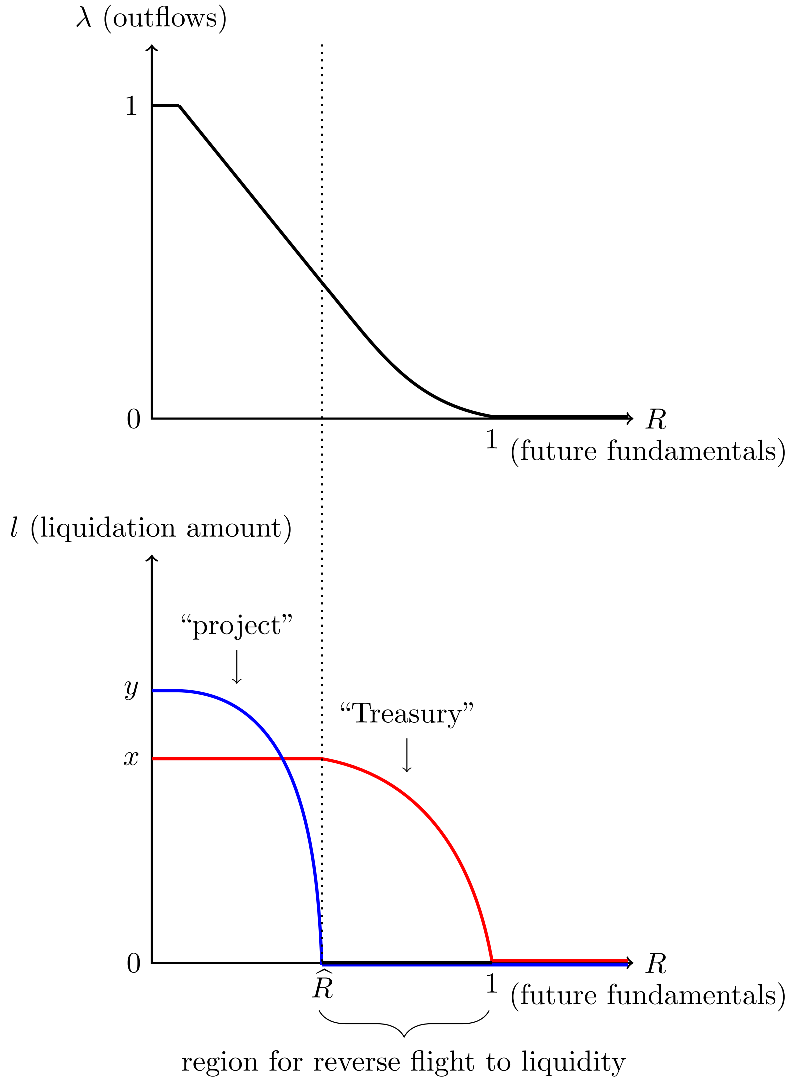

Figure 13: Reverse Flight to Liquidity

begin to deteriorate, resulting in reverse flight to liquidity. Specifically, $\widehat{R}$ denotes the cutoff at which outflows by late households require the fund to just exhaust its Treasury holdings.

We also note Proposition 1 is true regardless of fund NAV stickiness, that is, whether μ is zero or positive.[10] This observation has two realistic implications. On the one hand, it implies that our analysis of reverse flight to liquidity applies to real-world mutual funds whose NAVs are adjustable but may not be perfectly flexible. On the other hand, it suggests that even under policies such as swing pricing that help funds to flexibly adjust their NAVs, reverse flight to liquidity still arises

[10] As we mentioned above, this is true unless μ is too large in which case the fund effectively becomes a bank, which we address in Appendix A.4.

from mutual funds' liquidity transformation, in which case the underlying asset prices today cannot fully reflect future fundamentals fluctuations unless liquidation happens.

An immediate question of important empirical relevance is whether more illiquid funds with more sticky NAVs experience more or less outflows when reverse flight to liquidity occurs. We answer this question in the following proposition:

Proposition 2 (Fund NAV stickiness, fund flows, and reverse flight to liquidity)**.** *Consider a fund economy where reserve flight to liquidity happens in region $\Delta = (\widehat{R}, 1)$, and in which region outflows are given by $\widetilde{\lambda}(R)$ according to Proposition 1. Then for a given $R \in (\widehat{R}, 1)$, when μ increases, $\widetilde{\lambda}(R)$ increases, and the liquidation amount of the Treasury $l_x^*(R)$ also increases.*

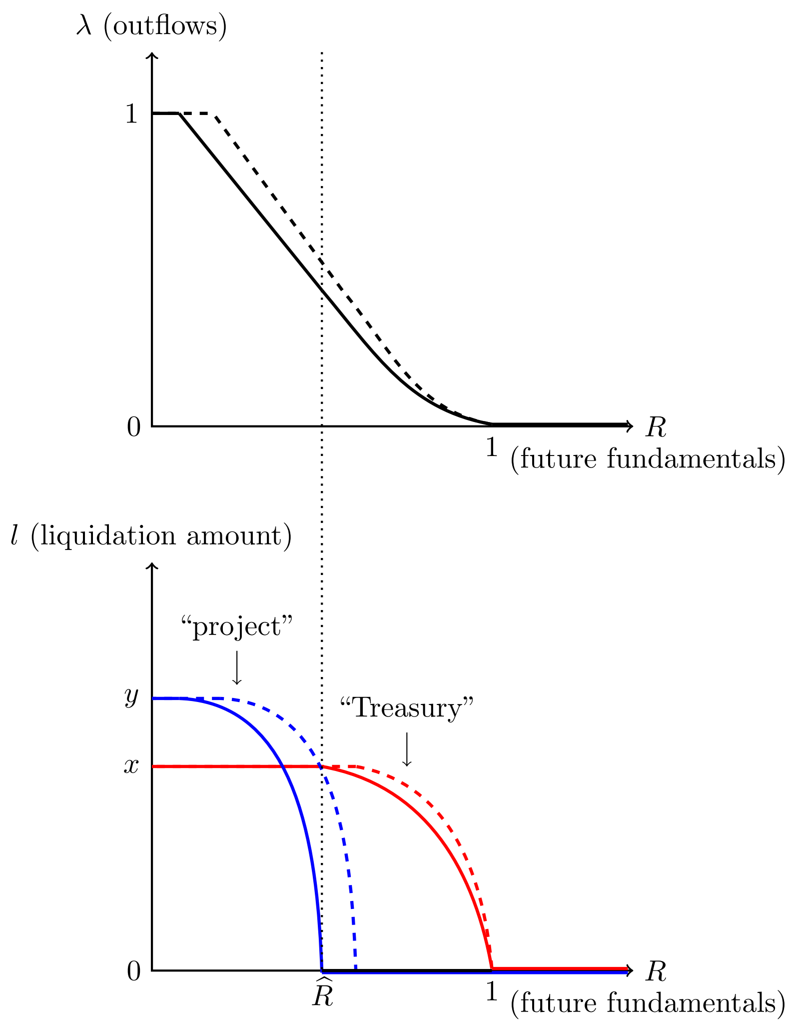

Figure 14: Fund NAV Stickiness, Fund Flows, and Reserve Flight to Liquidity

Proposition 2, illustrated by the changes from solid to dashed curves in Figure 14, implies that when reverse flight to liquidity occurs, illiquid funds with more sticky NAVs are subject to larger outflows, which ultimately lead to more Treasury liquidations. Intuitively, more sticky NAVs entitle redeeming households to a higher payment at $t = 1$ and defer some of the liquidation costs to $t = 2$, which generates a higher incentive for households to redeem $t = 1$ given the same fundamental news. Looking back, we already understand from Proposition 1 that funds subject to larger outflows have to liquidate more Treasuries when reverse flight to liquidity occurs. Thus, jointly interpreting Propositions 1 and 2 thus offers a plausible perspective to understand the aggregate trends in Figures 6 and **??**. We also provide more granular evidence below in the empirical analysis.

We highlight that the above Propositions 1 and 2 are intricately tied to mutual funds' use of demandable equity (despite that the NAV may be sticky) rather than banks' use of demandable debt in liquidity transformation. As long as NAVs adjust by incorporating liquidation costs, fund investors' payoff and redemption decisions continuously adjust to changes in expected future fundamentals. In contrast, bank debt whose promised contract value is fixed insulates withdrawal decisions from fundamentals fluctuations unless fundamental news is too bad and a bank run happens. In reality, the latter force is further strengthened by banks enjoying other government safety nets such as deposit insurance but mutual funds not. In Appendix A.4, we use a simple bank benchmark to illustrate that that reverse flight to liquidity more likely arises in equity-funded intermediaries, but less likely in debt-funded intermediaries like commercial banks.

Having analyzed how a mutual fund holding relatively liquid assets such as the Treasury may lead to reverse flight to liquidity in Propositions 1 and 2, we further consider why it makes sense for funds specialize in illiquid assets such as high-yield bonds and bank loans ever hold any Treasury at all, to what extent it affects the potential for reserve flight to liquidity going forward. The following proposition shows that, when the fund transforms more liquidity in the sense that its underlying project is more illiquid, it will optimally hold more of the Treasury ex-ante, which may trigger reverse flight to liquidity in a wider range of fundamentals ex-post:

Proposition 3 (Asset illiquidity and Treasury holdings). *When ϕ_y increases, the fund's optimal Treasury holding x^* increases.*

The intuition underlying Proposition 3 is fundamentally linked to the technology that mutual funds use to transform liquidity. As opposed to banks, mutual funds issue demandable equity who value is more sensitive to fundamentals fluctuations, and they do not enjoy any government liquidity backstops such as deposit insurances. Rather, they hold private liquid buffers, that is, the Treasury in the model, to support their liquidity transformation, and Proposition 3 intuitively suggests that transforming from a more illiquid underlying asset requires the fund to hold more liquid buffers.

Thus, Proposition 3 leads to an important implication that a mutual fund sector that transforms more liquidity also demands to hold more liquid assets and has the capacity to generate reverse flight to liquidity episodes in more states of the economy. Empirically, the US mutual fund sector has indeed been increasingly invested in illiquid asset categories. From this perspective, reverse flight to liquidity episodes may happen more easily today than in the past, and may become an increasingly regular phenomenon going forward.

A.3 Policy Implications

Our analysis of fund outflows, liquidations of illiquid assets, and the resulting reverse flight to liquidity phenomenon allows us to evaluate which ex-post policy interventions may help to reduce the severity of negative economic outcomes. To this end, we build on Proposition 1 and conduct comparative statics with respect to model parameters in the sub-game equilibrium at $t = 1$, taking the fund's portfolio as given. Our approach compares the outcomes with ex-post policy interventions, which correspond to the announcements of various asset purchase programs by the Federal Reserve in March and April 2020, to a counterfactual without those policy interventions. First, Corollary 1 explores the effects of a policy that improves investors' expectations of future fundamentals.

Corollary 1. *Given an economy with a distribution of fundamentals $G(R)$ and a date-0 fund position (x, y), if the economy has the potential for reverse flight to liquidity in the sense that there exists a region Δ as in Definition 1, then under an alternative distribution of fundamentals $G'(R)$ that first-order stochastically dominates $G(R)$:*

i). The expected outflows $\int \lambda'^*(R)dG'(R)$ and the expected flow-induced asset liquidations $\int l_x'^*(R)dG'(R)$ and $\int l_y'^*(R)dG'(R)$ all become smaller;

ii). The region for reverse flight to liquidity Δ' is unchanged but the likelihood of observing actual reverse flight to liquidity becomes smaller if $G'(R)$ further satisfies $\int_{\Delta'} G'(R) < \int_{\Delta'} G(R)$.

The first part of Corollary 1 implies that any policy that leads to an improved expectation of future fundamentals will help to reduce fund outflows, which will in turn reduce pre-mature liquidations of both the Treasury and the project. This observation directly follows from the equilibrium characterization in Proposition 1 that $w^*(R)$, $l_x^*(R)$ and $l_y^*(R)$ are decreasing in R, but that those three functions do not directly depend on $G(R)$ given the portfolio positions (x, y) in equilibrium.

However, whether the observed phenomenon of reverse flight to liquidity becomes less likely further depends on how the policy improves expectations of fundamentals, as shown in the second part of Corollary 1. This is because the region for reverse flight to liquidity $[\widehat{R}, 1]$ does not depend on $G(R)$ in equilibrium. Intuitively, because reverse flight to liquidity occurs in the intermediate region $[\widehat{R}, 1]$, it will be less likely to happen if the policy improves the upside in the sense of moving the probability mass of $G(R)$ from $[\widehat{R}, 1]$ to $[1, +\infty)$. Rather, if the policy only improves the downside in the sense of moving the probability mass of $G(R)$ from $[0, \widehat{R}]$ to $[\widehat{R}, 1]$, it may actually increase the likelihood of observing reverse flight to liquidity.

Next, Corollary 2 considers the effect of a policy that aims to support the liquidity of relatively less illiquid assets that mutual funds may potentially use as a liquid buffer:

Corollary 2. *Given an economy with a level of Treasury illiquidity ϕ_x and a date-0 fund position (x, y), if the economy has the potential for reverse flight to liquidity in the sense that there exists an region Δ as in Definition 1, then under a lower level of Treasury illiquidity $\phi_x' < \phi_x$:*

i). The expected flow-induced asset liquidations $\int l_x'^*(R)dG(R)$ and $\int l_y'^*(R)dG(R)$ become smaller but the effect on expected outflows is ambiguous.

ii). The region for reverse flight to liquidity $\Delta = [\widehat{R}', 1]$ becomes larger (i.e., $\widehat{R}'$ is smaller).

Corollary 2 suggests that policies supporting the Treasury's liquidity may also help reduce premature liquidations of both the Treasury and the project. It follows from the equilibrium characterization in Proposition 1 that $\widehat{R}$, $l_x^*(R)$ and $l_y^*(R)$ all increase in ϕ_x. However, the impact on fund outflows us ambiguous because the channel differs from that underlying Corollary 1. Importantly, there is no improvement in the expected distribution of fundamentals. Instead, when the Treasury becomes more liquid, a smaller amount of the Treasury can be sold to meet the same redemption requests i.e., to weather the same shock to fundamentals. As a result, the region in which reverse flight to liquidity occurs becomes larger. Nevertheless, pre-mature liquidation of the project is reduced because the fund only starts to liquidate the project in a worse state of the economy than in the counterfactual case without the policy.

A.4 Bank Benchmark

To demonstrate how mutual fund liquidity transformation uniquely contributes to reverse flight to liquidity, we provide a benchmark economy in which a comparable bank transforms liquidity by investing in illiquid assets and issuing demandable debt. We show that reverse flight to liquidity, defined by Definition 1, does not occur in this bank economy.

The main difference between the bank benchmark and the mutual fund economy lies in the contract form of the intermediary. Rather than offering an NAV-based equity contract, the bank offers a demandable debt contract (c_1, c_2) that is subject to a sequential service constraint at $t = 1$, where

$$q(\lambda) = \frac{(1-\phi_x)x + (1-\phi_y)y}{\lambda c_1} \tag{A.2}$$

is the probability of withdrawing households to be served when the bank fails and the sequential service constraint is binding. At $t = 0$, the bank also chooses the optimal portfolio (x, y) to maximize ex-ante expected household utility. Notice that although the value of fund equity may adjust with some stickiness, the promised value of bank debt is fixed at the outset.

We use the global games technique following Goldstein and Pauzner (2005) to pin down the probability of panic runs and link it to fundamental news. To this end, we assume θ to be uniformly distributed, and that ε_i, the i.i.d. noise term, is uniformly distributed over $[-\varepsilon, \varepsilon]$, where ε is arbitrarily small. This guarantees the existence of a threshold R^* below which bank runs uniquely occur. We can then show that reverse flight to liquidity does not occur in this benchmark economy with bank liquidity transformation.

Proposition 4. *Given any date-0 bank position, the promised debt value c_1, and the signal s_i received by households at $t = 1$, there exists a unique run threshold $R^* > 0$. There does not exist any non-zero-measure set Δ in which $l^*(R)$ strongly decreases in R or $l_x^*(R) > l_y^*(R)$, that is, reverse flight to liquidity does not happen according to Definition 1.*

We graphically illustrate Proposition 4 in Figure A1. The economic intuition follows from the nature of banks using demandable debt to transform liquidity. Unless panic runs occur, late

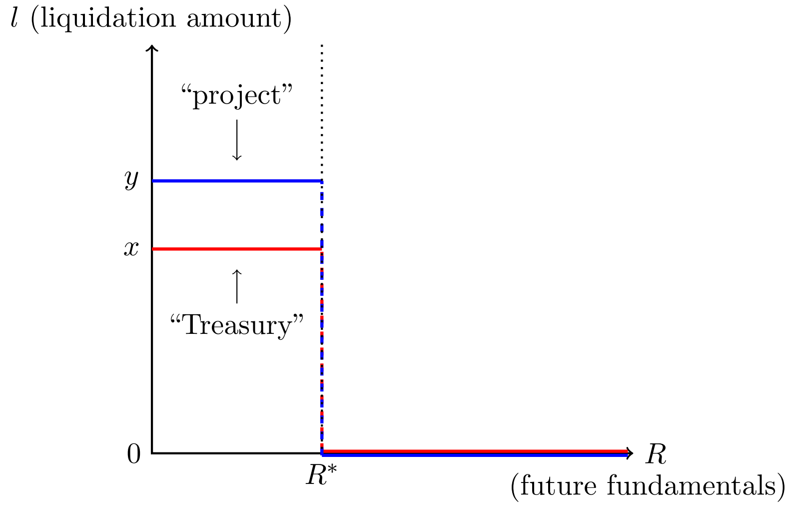

Figure A1: No Reverse Flight to Liquidity in Bank Benchmark

households' withdrawals never directly respond to news about future fundamentals because debt promises a fixed value. Early households' withdrawals, if any, are independent of news about future fundamentals as well. Therefore, in the absence of runs, deteriorating news about fundamentals do not induce changes in withdrawal requests nor asset liquidations. When panic runs occur, investors withdraw from the bank altogether, leading to a complete and thus proportional liquidation of all bank assets. In either case, the bank does not sell the Treasury before selling the project, and there does not exist a region in which the liquidation amount of the Treasury continuously increases with worsening prospects about future fundamentals.

Although bank runs in reality may be more gradual in response to fundamental deteriorations (for example, see He and Manela (2016) for a theoretical analysis and Artavanis, Paravisini, Robles-Garcia, Seru and Tsoutsoura (2019) for empirical evidence), we note that the "all-or-nothing" feature of asset liquidation by banks in Proposition 4 serves as a benchmark to understand the patterns of asset sales in reality. The general message is that the fixed value promised by bank deposits induce relatively discontinuous withdrawals with respect to changes in fundamentals, in contrast to the continuously increasing redemptions with worsening fundamentals in the case of fund equity with a sufficiently flexible NAV. Discontinuous withdrawals render the sequential liquidation of increasingly illiquid assets less relevant: before fundamentals reach the run threshold, withdrawals and liquidations are minimal; after the run threshold is crossed, withdrawals tend to induce more complete (and thus proportional) asset sales. In reality, the run threshold may be further pushed down thanks to banks enjoying government liquidity backstops and deposit insurances that mutual funds do not have access to, and banks may even experience inflows during economic crises (Gatev and Strahan, 2006), which all help explain why banks may be less likely to generate reverse flight to liquidity outside of the model.

Jointly interpreting Propositions 1 and 4 offers a plausible explanation for why there was pronounced reverse to liquidity during the Covid-19 crisis but not during the 2008-2009 financial crisis. It is the increased importance of equity-issuing bond mutual funds relative to deposit-funded banks (see Figure 1), which has rendered investors' redemptions and intermediaries' asset sales more sensitive to fluctuations in economic fundamentals. In particular, mutual funds' pecking order of liquidation induces concentrated and systematic sales of more liquid assets, posing strains to traditionally liquid asset markets.

B Liquidity Transformation by Mutual Funds versus Banks

Comparing the effects of liquidity transformation by mutual funds versus commercial banks is challenging. The ideal environment in which we observe mutual funds intermediating a given set of assets and banks intermediating the same set of assets does not exist. Instead, we create a matched sample of commercial banks and loan mutual funds that resemble each other in their asset composition as a laboratory to compare and contrast the consequences of their liquidity transformation. Specifically, we use the Covid-19 crisis as a shock to fundamentals to show that demandable equity-issuing funds uniquely contribute to the reverse flight to liquidity phenomenon. This is achieved in two steps: (1) funds experienced increased outflows relative to banks given the same shock to fundamentals; and (2) funds disproportionately sold liquid assets over less liquid assets relative to banks.

We start with all US open-end loan funds, who invest in corporate loans similar to commercial banks' loans. Then, we match one commercial bank to each loan fund without replacement using a propensity score. Matching criteria include cash and cash equivalents, government bonds, and loans as a proportion of total assets in 2019Q1. Table 10 shows summary statistics for the matched sample, which comprises of 60 funds and 60 banks. Overall, the match performs well along observable dimensions. The proportion of loans in loan funds averages 79.1%, which is very close to the 77.2% in the matched sample of commercial banks. The proportions of government securities and cash in loan funds are 1.5% and 3.1%, which are quite similar to those of matched banks. Loan funds have slightly more other securities, which include MBS, ABS, corporate equity, and corporate bonds.

Table 10: Portfolio Composition of Loan Funds and Banks in the Matched Sample

	Bank	Fund	Difference	t-stats	# of banks	# of funds
Loans	77.224	79.125	-1.901	-0.594	60	60
Government securities	1.484	2.014	-0.530	-0.894	60	60
Cash and cash equivalent	3.062	2.217	0.845	1.252	60	60
Other securities	9.022	14.396	-5.374	-2.175	60	60
Miscellaneous	9.208	2.288	6.920	4.784	60	60

This table reports the average portfolio weights of a matched sample of loan funds and commercial banks. The sample is matched by constructing a propensity score based on the portfolio weights of cash, government bonds, and loans. "Other securities" include MBS, ABS, municipal bonds, corporate equity and bond. "Miscellaneous" include assets that cannot be classified into the above categories, such as real estate investments, premises, and fixed assets. The sample period is 2019Q1. Data source: CRSP and Call Reports.

Next, we examine outflows at loan funds and their matched banks leading up to the Covid-19 crisis. Figure 15 plots the average quarterly redemptions and shows that the level of redemptions in the two samples remains relatively constant throughout 2019, which was a period without major disruptions to the real economy.[11] This observation is consistent with the theory because even with adjusting NAVs, changes in the incentive to redeem are limited when shocks to expected future fundamentals are small to begin with. For bank deposits promising a fixed value, withdrawal spikes are even less likely during this period as the threat of bank defaults is remote without major expected deteriorations in the economy.

In 2020Q1, however, the rate of redemptions at loan funds increasingly diverged from that at their matched banks (see Figure 15). The increase in redemptions from around 5% in 2019Q4 to 10% in 2020Q1 at loan funds follows a worsening of expected future fundamentals, which lowered the expected long-run return of the fund and induces heightened investor redemptions. At banks, however, outflows largely remained at their 2019 levels. The stability of flows at banks arises from their use of demandable debt. Specifically, the worsening of fundamentals has not yet crossed the threshold of panic runs so that investors still expect to obtain the same fixed interest

[11]Note that the level of redemptions for the two samples is stable yet different. This could be for a variety of reasons, including a different long-run growth rate of the sector, which is not in our benchmark model. For this reason, we focus on interpreting the deviations in redemptions relative to their overall levels.

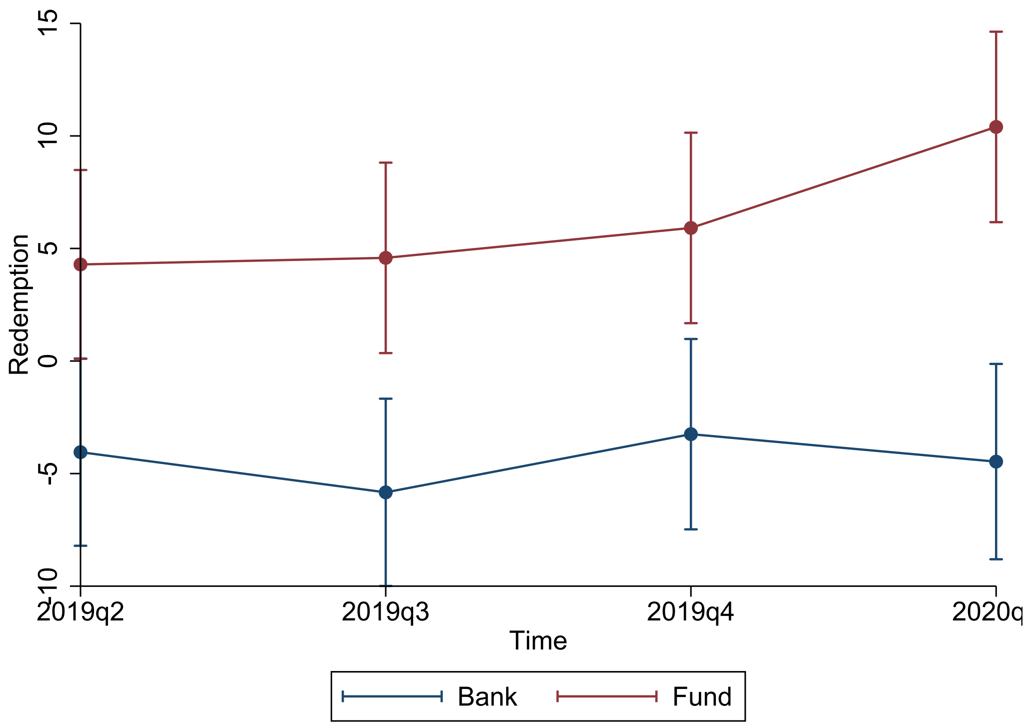

Figure 15: Redemptions at Loan Funds and Banks (Matched Sample)
This graph plots the quarterly redemptions (in percentages) of uninsured bank deposits and fund shares for a matched sample of loan funds and commercial banks. The solid dots represent average redemptions and the marked intervals represent the 5th and 95th percentile of redemptions. The sample is matched by constructing a propensity score based on the portfolio weights of cash, government bonds, and corporate loans. The sample period is from 2019Q2 to 2020Q1. Data source: Morningstar and Call Reports.

on deposits and are not attracted to more withdrawals. Notice that the absence of increased withdrawals at banks is the first step for showing that liquidity transformation through banks eliminates reverse flight to liquidity. After all, without heightened withdrawals, there is no need for selling assets (including liquid ones) in the first place.

In reality, the likelihood of bank runs may also be influenced by regulatory features such as deposit insurance. To address this concern and to formally test the difference in redemptions at banks versus loan funds during the Covid-19 crisis, we perform a range of difference-in-difference estimates on outflows. Loan funds constitute the treatment group because our theory predicts increased outflows for demandable equity funded intermediaries following shocks to fundamentals. The matched sample of banks are exposed to the same shocks to fundamentals through their similar asset holdings but should not experience increased withdrawals because they promise a fixed payoff to depositors.[12] Hence, they are the control group. We take the shock to fundamentals to start in 2020Q1, which, as evident from Figure 15, marks the beginning of increased redemptions. Notice that the stability in redemptions before 2020Q1 points to the unanticipated nature of the Covid-19 crisis. If investors expected future deteriorations in fundamentals earlier, redemption requests would have surged sooner as well.

Columns (1) to (3) in Table 11 state the difference-in-difference estimates for total redemptions of bank deposits and fund shares. We find that following the Covid-19 shock, loan funds suffer a 8.8% higher jump in redemptions than demandable-debt funded banks holding similar assets. The statistical and economic significance of our results is unchanged by the inclusion of bank/fund fixed effects and time fixed effects. The results are also robust to limiting the analysis to withdrawals of uninsured deposits only, suggesting that the difference in redemptions at banks versus funds cannot be explained by deposit insurance alone.

[12] To be precise, this statement holds if the threshold for bank runs is not yet crossed, which was realistically the case during the first stages of the Covid-19 crisis in March 2020.

Table 11: Redemptions: Loan Funds versus Banks

	(1) Total	(2) Insured	(3) Uninsured
Post*Treat	8.755***	9.616***	5.527***
	[0.706]	[0.908]	[0.700]
Bank/Fund F.E.	Yes	Yes	Yes
Time F.E.	Yes	Yes	Yes
Observations	465	465	465
Adj. R-squared	0.243	0.234	0.212

This table presents difference-in-difference estimates of redemptions in a matched sample of loan funds and commercial banks. The sample period is from 2019Q2 to 2020Q1. For loan funds, redemptions are measured as a percentage of total assets. For commercial banks, columns (1) to (3) measure redemptions of total deposits, insured deposits, and uninsured deposits respectively. *Post* is a dummy variable equal to one in 2020Q1 and *Treat* is a dummy variable equal to one for loan funds. The sample is matched by constructing a propensity score based on the portfolio weights of cash, government bonds and corporate loans. The standard errors in brackets are clustered by quarter. Data source: CRSP and Call Reports.

We further examine the effects of redemptions on portfolio compositions. Table 12 shows the difference-in-difference estimates for the percentage of liquid assets and corporate loans in funds' and banks' portfolio, where liquid assets are the sum of cash, cash equivalents, and Treasuries. As before, loan funds make up the treatment group and 2020Q1 is the post period. The result in column (1) indicates that following the Covid-19 shock, loan funds reduced their holdings of liquid assets by 1.7% more than commercial banks with similar portfolio compositions before the shock. At the same time, the proportion of corporate loans in the portfolio of loan funds expanded by 1.6% more than that at commercial banks with similar portfolio compositions. One concern is that the loan volumes at commercial banks are mechanically driven by firms increasing their use of credit lines during the Covid-19 shock. To this end, we rerun our analysis by considering the sum of loans on balance sheet and unused loan commitments and obtain similar findings as in the baseline in column (3). Taken together, our results suggest that demandable-equity-funded loan funds disproportionately sold off liquid assets over illiquid assets in meeting heightened redemptions requests following the Covid-19 shock. Consistent with our model predictions, this behavior was unique because deposit-funded banks that held similar pre-Covid-19 portfolios experienced relatively limited changes in withdrawals and portfolio holdings.

Table 12: Portfolio Composition: Loan Funds versus Banks

	(1)	(2)	(3)
	Liquid assets	Loans	Loans & commit.
Post*Treat	-1.745**	1.580***	1.883**
	[0.540]	[0.253]	[0.326]
Bank/Fund F.E.	Yes	Yes	Yes
Time F.E.	Yes	Yes	Yes
Observations	465	465	465
Adj. R-squared	0.589	0.972	0.971

This table presents difference-in-difference estimates of portfolio composition in a matched sample of loan funds and commercial banks. The sample period is from 2019Q2 to 2020Q1. Columns (1) measure the percentage of liquid assets, which is the sum of cash, cash equivalents, and Treasury securities. Columns (2) measures the percentage of corporate loans. Columns (3) measures the percentage of corporate loans plus unused loan commitment. *Post* is a dummy variable equal to one in 2020Q1 and *Treat* is a dummy variable equal to one for loan funds. The sample is matched by constructing a propensity score based on the portfolio weights of cash, government bonds and corporate loans. The standard errors in brackets are clustered by quarter. Data source: Morningstar and Call Reports.

C Proofs

Proof of Proposition 1. The proof proceeds in three steps. First, we derive all the NAV equations and the equilibrium condition. Second, we solve for and characterize the equilibrium redemptions $\lambda^*(R)$ and asset liquidations $l_x^*(R)$ and $l_y^*(R)$. Third, we verify that the proposed fundamentals cutoff $\widehat{R}$ indeed determines the point at which the fund starts to liquidate its illiquid project, which ultimately determines the fundamentals region of reverse flight to liquidity Δ. We consider the case of $\mu = 0$ when explicitly solve for the equilibrium and show that the equilibrium structure is preserved when μ is positive but not too large by a standard continuity argument.

STEP 1. According to the NAV rule (A.1) and the pecking order of liquidation, at $t = 1$, the fund's end-of-day NAV is determined by

$$NAV_1(\lambda) = \begin{cases} x - (1-\mu)\phi_x l_x + y & \text{if} \quad l_x > 0 \text{ and } l_y = 0\,, \\ x - (1-\mu)\phi_x x + y - (1-\mu)\phi_y l_y & \text{if} \quad l_x = x \text{ and } 0 < l_y < y\,, \\ x - \phi_x x + y - \phi_y y & \text{if} \quad l_x = x \text{ and } l_y = y\,, \end{cases} \tag{C.1}$$

where both l_x and l_y are functions of λ in equilibrium. Note that when the mutual fund is still solvent (captured by lines 1 and 2), the fund NAV may be higher than the value of the fund's underlying assets if NAV is stale, i.e., $\mu > 0$. When the fund is fully liquidated (captured by line 3), however, every household will split the true valuation of the fund equally.

At the same time, the fund needs to liquidate assets to a point such that the raised consumption goods are just enough to meet λ redemptions at NAV_1. Hence, NAV_1 can also be expressed as:

$$\lambda NAV_1(\lambda) = \begin{cases} (1-\phi_x)l_x & \text{if} \quad l_x > 0 \text{ and } l_y = 0\,, \\ (1-\phi_x)x + (1-\phi_y)l_y & \text{if} \quad l_x = x \text{ and } l_y > 0\,, \end{cases} \tag{C.2}$$

where the LHS is the total amount of consumption goods distributed to redeeming households at $t = 1$ and the RHS is the amount of raised consumption goods from liquidation, both evaluated at the end of $t = 1$.

Having analyzed NAV_1, the fund NAV at $t = 2$ is determined accordingly by

$$NAV_2(\lambda) = \begin{cases} \dfrac{1}{1-\lambda}(x - l_x + yR) & \text{if} \quad l_x > 0 \text{ and } l_y = 0\,, \\ \dfrac{1}{1-\lambda}(y - l_y)R & \text{if} \quad l_x = x \text{ and } l_y > 0\,. \end{cases} \tag{C.3}$$

We can now characterize late households' optimal redemption decisions given their signal s_i:

$$\begin{cases} \lambda = 0 & \text{if} \quad u(NAV_1(\lambda)) < E[u(NAV_2(\lambda))|s_i]\,, \\ \lambda \in (0,1) & \text{if} \quad u(NAV_1(\lambda)(1-\kappa\lambda)) = E[u(NAV_2(\lambda))|s_i]\,, \\ \lambda = 1 & \text{if} \quad u(NAV_1(\lambda)(1-\kappa\lambda))) > E[u(NAV_2(\lambda))|s_i]\,. \end{cases}$$

Note that when s_i is an almost perfect signal about R, there is no fundamental uncertainty between $t = 1$ and $t = 2$, and thus this problem translates to:

$$\begin{cases} \lambda = 0 & \text{if} \quad NAV_1(\lambda) < NAV_2(\lambda)\,, \\ \lambda \in (0,1) & \text{if} \quad NAV_1(\lambda)(1-\kappa\lambda) = NAV_2(\lambda)\,, \\ \lambda = 1 & \text{if} \quad NAV_1(\lambda)(1-\kappa\lambda) > NAV_2(\lambda)\,. \end{cases} \tag{C.4}$$

Step 2. We now show that the optimal redemption is given by

$$\lambda^*(R) = \begin{cases} 0 & \text{if} \quad R \geq 1\,, \\ \widetilde{\lambda}(R) & \text{if} \quad \widehat{R} \leq R < 1\,, \\ \dfrac{1-R}{\kappa} & \text{if} \quad 1-\kappa \leq R < \widehat{R}\,, \\ 1 & \text{if} \quad 0 \leq R < 1-\kappa\,, \end{cases} \tag{C.5}$$

where $\widehat{R}$ is given by (C.9). Particularly, $\widetilde{\lambda}(R)$ strictly decreases in R and is continuous at both 0 and $\widehat{R}$, and thus $\lambda^*(R)$ decreases in R globally. The closed-form expression of $\widetilde{\lambda}(R)$ is given by (C.10) below.

Because the fund follows the pecking order of liquidation, we first consider the case of $l_x > 0$ and $l_y = 0$ in which the fund liquidates the Treasury only. By NAV equations (C.1) and (C.2), we can express l_x as a function of λ:

$$l_x(\lambda) = \frac{\lambda}{1-\phi_x+\phi_x\lambda}\,. \tag{C.6}$$

which implies that

$$NAV_1(\lambda) = 1 - \frac{\phi_x\lambda}{1-\phi_x+\phi_x\lambda}\,, \tag{C.7}$$

and by NAV equation (C.3)

$$NAV_2(\lambda) = \frac{1}{1-\lambda}\left(x - \frac{\lambda}{1-\phi_x+\phi_x\lambda} + (1-x)R\right)\,, \tag{C.8}$$

both being functions of λ.

Plugging equations (C.7) and (C.8) into the equilibrium condition (C.4) gives a quadratic equation of λ. Solving that quadratic equation gives two roots:

$$\frac{\kappa(1-\phi_x)-\phi_x(1-x)(1-R)\pm\sqrt{(\kappa(1-\phi_x)-\phi_x(1-x)(1-R))^2-4\kappa(1-\phi_x)^2(1-x)(1-R)}}{2\kappa(1-\phi_x)}.$$

Notice that when $R>\widehat{R}$, where

$$\widehat{R}\doteq\max\left\{1-\frac{\kappa(1-\phi_x)x}{(1-\phi_x)x+(1-x)},0\right\}, \tag{C.9}$$

it must be that $\kappa(1-\phi_x)-\phi_x(1-x)(1-R)>0$. Hence, we pick the root that always lies in the interval of $(0,1)$:

$$\lambda^*(R)=\widetilde{\lambda}(R)=\frac{\kappa(1-\phi_x)-\phi_x(1-x)(1-R)-\sqrt{(\kappa(1-\phi_x)-\phi_x(1-x)(1-R))^2-4\kappa(1-\phi_x)^2(1-x)(1-R)}}{2\kappa(1-\phi_x)}, \tag{C.10}$$

which is strictly decreasing in R. Note that (C.6) implies that $l_x(\lambda)$ strictly increases in λ, which thus immediately implies that $l_x^*(R)$ strictly decreases in R in this case. Also note that $\widetilde{\lambda}(0)=0$, implying that $\lambda^*(R)=0$ and $l_x^*(R)=0$ for $R\geq 1$.

We then consider the other case of $l_x=x$ and $l_y>0$ in which the fund has already exhausted its Treasury and liquidates its project. In this case, combining NAV equations (C.1) and (C.2) yields

$$l_y(\lambda)=\frac{\lambda-x+\phi_x x(1-\lambda)}{1-\phi_y+\phi_y\lambda}. \tag{C.11}$$

which combined with (C.3) further yields

$$NAV_2(\lambda)=NAV_1(\lambda)\cdot R. \tag{C.12}$$

Then plugging equation (C.12) into the equilibrium condition (C.4) immediately yields

$$\lambda^*(R)=\frac{1-R}{\kappa}, \tag{C.13}$$

which is also decreasing in R and subject to $\lambda^*(R)\leq 1$. Similarly, note that (C.11) implies that $l_y(\lambda)$ increases in λ, which thus immediately implies that $l_y^*(R)$ decreases in R in this case. Note that $\lambda^*(1-\kappa)=1$ when $\kappa\leq 1$, implying that $\lambda^*(R)=1$ and $l_y^*(R)=y$ when $R\leq 1-\kappa$.

Step 3. We now verify the existence of $\widehat{R}$. There are also two cases depending on the magnitude of κ. In the first case of $0 < \kappa < 1 + (1-x)/(1-\phi_x)x$, we have $\widehat{R} > 0$, and we conjecture that at $\widehat{R}$ outflows would just exhaust the fund's Treasury holdings x. We need to verify that

$$l_x^*(\lambda^*(\widehat{R})) = x\,. \tag{C.14}$$

To show this, notice that both (C.10) and (C.13) give

$$\lambda^*(\widehat{R}) = \frac{(1-\phi_x)x}{(1-\phi_x)x + (1-x)}$$

which then by (C.6) immediately yields (C.14). Because both $l_x^*(R)$ and $l_y^*(R)$ decrease in R as Step 1 shows, it thus must be that $l_x^*(R) < x$ and $l_y^*(R) = 0$ when $\widehat{R} < R < 1$ and that $l_x^*(R) = x$ and $l_y^*(R) > 0$ when $R < \widehat{R}$. Combining this observation with the characterization of $\lambda^*(R)$ in Step 1 immediately gives the full expression of (C.5).

In the second case of $\kappa > 1 + (1-x)/(1-\phi_x)x$, we have $\widehat{R} = 0$. In this case, the fund never exhaust its Treasury holdings, and by the pecking order of liquidation never liquidates the project. This implies that

$$\lambda^*(R) = \begin{cases} 0 & \text{if} \quad R \geq 1\,, \\ \widetilde{\lambda}(R) & \text{if} \quad 0 \leq R < 1\,, \end{cases}$$

which is nested by (C.5).

Note that by construction, in both cases discussed above $0 \leq \widehat{R} < 1$, implying that the region $\Delta = (\widehat{R}, 1)$ must has a strictly positive measure.

Finally, notice that the equilibrium outcomes characterized above are interior solutions to the functional system of $F(NAV_1(\lambda(R)), NAV_2(\lambda(R), R)) = 0$, which consists of equations (C.1), (C.2), (C.3), and (C.4). Since both $NAV_1(\lambda(R))$ and $NAV_2(\lambda(R), R))$ are continuous in μ, by a standard continuity argument those interior solutions must be continuous in μ at $\mu = 0$, which implies that the equilibrium structure is preserve when μ is not too large. ∎

Proof of Proposition 2. Since we focus on the region of reverse flight to liquidity when it happens, we only analyze the case of $l_x > 0$ and $l_y = 0$ in which the fund liquidates the Treasury only. By NAV equations (C.1) and (C.2), we can express l_x as a function of λ:

$$l_x(\lambda) = \frac{\lambda}{1 - \phi_x + (1-\mu)\phi_x \lambda}\,.$$

which implies that

$$NAV_1(\lambda) = 1 - \frac{(1-\mu)\phi_x \lambda}{1-\phi_x+\phi_x\lambda}\,, \tag{C.15}$$

and by NAV equation (C.3)

$$NAV_2(\lambda) = \frac{1}{1-\lambda}\left(x - \frac{\lambda}{1-\phi_x+(1-\mu)\phi_x\lambda} + (1-x)R\right)\,, \tag{C.16}$$

both being functions of λ.

Plugging equations (C.15) and (C.16) into the equilibrium condition (C.4) gives a quadratic equation of λ. Similarly to the analysis in the proof of Proposition 1, solving that quadratic equation and selecting the positive root smaller than one yields:

$$\widetilde{\lambda}(R;\mu) = \frac{C_1(R;\mu) - \sqrt{C_1^2(R;\mu) - 4\kappa(1-\phi_x)^2(1-x)(1-R)}}{2\kappa(1-\phi_x)}\,,$$

where

$$C_1(R;\mu) = \kappa(1-\phi_x) - \phi_x\left(1-(1-\mu)(x+(1-x)R)\right)\,.$$

Take first-order derivative with respect to μ:

$$\frac{\partial\widetilde{\lambda}(R;\mu)}{\partial\mu} = \frac{1}{2\kappa(1-\phi_x)}\left(\frac{(\phi_x((1-x)(1-R(1-\mu))+\mu x+\kappa)-\kappa)(x+(1-x)R)}{\sqrt{C_1^2(R;\mu)-4\kappa(1-\phi_x)^2(1-x)(1-R)}} - x - R + xR\right)\,,$$

which is strictly positive when $R > \widehat{R}$ and $C_1^2(R;\mu) > 4\kappa(1-\phi_x)^2(1-x)(1-R)$, both being satisfied when reserve flight to liquidity happens, yielding the result. ∎

Proof of Proposition 3. We consider the case of $\mu = 0$ and the result follows for a sufficiently small μ following a standard continuity argument. The representative fund solves the optimal portfolio allocation (x, y) at $t = 0$ to maximize the expected utility of all households:

$$\max_x E\left[\lambda u(NAV_1(\lambda)(1-\kappa\lambda)) + (1-\lambda)u(NAV_2(\lambda))\right]$$

By Proposition 1, the objective function can be expressed piece-wise in explicit form as:

$$
\begin{aligned}
W &= \int_0^{1-\kappa} u\left(NAV_1(1)(1-\kappa)\right) dG(R) \\
&+ \int_{1-\kappa}^{\widehat{R}} \left(\frac{1-R}{\kappa} u\left(NAV_1\left(\frac{1-R}{\kappa}\right) R\right) + \left(1 - \frac{1-R}{\kappa}\right) u\left(NAV_2\left(\frac{1-R}{\kappa}\right)\right)\right) dG(R) \\
&+ \int_{\widehat{R}}^{1} \left(\widetilde{\lambda}(R) u\left(NAV_1\left(\widetilde{\lambda}(R)\right)\left(1-\kappa\widetilde{\lambda}(R)\right)\right) + \left(1-\widetilde{\lambda}(R)\right) u\left(NAV_2\left(\widetilde{\lambda}(R)\right)\right)\right) dG(R) \\
&+ \int_1^{+\infty} u\left(NAV_2(0)\right) dG(R)\,,
\end{aligned}
\tag{C.17}
$$

in which $NAV_1(\lambda)$ and $NAV_2(\lambda)$ are given by (C.1) and (C.3) and are both continuous in μ.

Notice that $\lambda^*(R)$ is continuous in R at $\widehat{R}$, the expected utility must be continuous in R at $\widehat{R}$ as well. Thus, despite $\widehat{R}$ being a function of x, taking the first order condition with respect to x yields:

$$
\begin{aligned}
f = \frac{\partial W}{\partial x} &= \int_0^{1-\kappa} (1-\kappa)(\phi_y - \phi_x) u'\left((1-\kappa)((\phi_y-\phi_x)x + (1-\phi_y))\right) dG(R) \\
&+ \int_{1-\kappa}^{\widehat{R}} R \left(\frac{1-R}{\kappa} \frac{\phi_y - \phi_x}{1-\phi_y(1-\lambda^*(R))} u'\left(1 + \frac{(\phi_y-\phi_x)x - \phi_y(1-\lambda^*(R)}{1-\phi_y(1-\lambda^*(R))}\right)\right. \\
&\quad \left. + \frac{(1-\lambda^*(R))(\phi_y-\phi_x)}{1-\phi_y(1-\lambda^*(R))} u'\left(\frac{\kappa}{\kappa-(1-R)} \frac{(1-\lambda^*(R))((\phi_y-\phi_x)x + (1-\phi_y)}{1-\phi_y(1-\lambda^*(R))}\right)\right) dG(R) \\
&+ \int_{\widehat{R}}^{1} \left(-\kappa \frac{\partial \widetilde{\lambda}(R)}{\partial x}(1-\phi_x l_x(\widetilde{\lambda}(R))) u'\left((1-\kappa\widetilde{\lambda}(R))(1-\phi_x l_x(\widetilde{\lambda}(R)))\right)\right) dG(R) \\
&+ \int_1^{+\infty} (1-R) u'\left(x(1-R)+R\right) dG(R) \\
&= 0\,,
\end{aligned}
$$

where by Proposition 1 there is $\lambda^*(R) = (1-R)/\kappa$ when $1 < R < 1-\kappa$ and $\widetilde{\lambda}(R)$ and $l_x(\widetilde{\lambda}(R))$ are given in (C.10) and (C.6) when $\widehat{R} < R < 1$. Consider:

$$
\begin{aligned}
\frac{\partial f}{\partial x} &= \int_0^{1-\kappa} \underbrace{(1-\kappa)^2(\phi_y-\phi_x)^2 u''(\cdot)}_{<0}\, dG(R) \\
&+ \int_{1-\kappa}^{\widehat{R}} \underbrace{\left(\left(\frac{(1-\lambda^*(R))(\phi_y-\phi_x)R}{1-\phi_y(1-\lambda^*(R))}\right)^2 + \frac{1-R}{\kappa}\left(\frac{(\phi_y-\phi_x)R}{1-\phi_y(1-\lambda^*(R))}\right)^2\right) u''(\cdot)}_{<0}\, dG(R) \\
&+ \underbrace{\begin{array}{l}\widehat{R}\left(\dfrac{1-\widehat{R}}{\kappa}\dfrac{\phi_y-\phi_x}{1-\phi_y(1-\lambda^*(\widehat{R}))}u'\left(1+\dfrac{(\phi_y-\phi_x)x-\phi_y(1-\lambda^*(\widehat{R}))}{1-\phi_y(1-\lambda^*(\widehat{R}))}\right)\right. \\ \left. +\dfrac{(1-\lambda^*(\widehat{R}))(\phi_y-\phi_x)}{1-\phi_y(1-\lambda^*(\widehat{R}))}u'\left(\dfrac{\kappa}{\kappa-(1-\widehat{R})}\dfrac{(1-\lambda^*(\widehat{R}))((\phi_y-\phi_x)x+(1-\phi_y))}{1-\phi_y(1-\lambda^*(\widehat{R}))}\right)\right)\dfrac{\partial \widehat{R}}{\partial x}\cdot\dfrac{dG(R)}{dR}\end{array}}_{<0} \\
&+ \int_{\widehat{R}}^1 \underbrace{-\kappa(1-\phi_x l_x(\widetilde{\lambda}(R)))\frac{\partial^2\widetilde{\lambda}(R)}{\partial x^2}u'(\cdot) + \kappa^2(1-\phi_x l_x(\widetilde{\lambda}(R)))\left(\frac{\partial\widetilde{\lambda}(R)}{\partial x}\right)^2 u''(\cdot)}_{<0}\, dG(R) \\
&- \underbrace{\left(-\kappa\frac{\partial\widetilde{\lambda}(\widehat{R})}{\partial x}(1-\phi_x l_x(\widetilde{\lambda}(\widehat{R})))u'\left((1-\kappa\widetilde{\lambda}(\widehat{R}))(1-\phi_x l_x(\widetilde{\lambda}(\widehat{R})))\right)\right)\frac{\partial \widehat{R}}{\partial x}\cdot\frac{dG(R)}{dR}}_{>0} \\
&+ \int_1^{+\infty} \underbrace{(1-R)^2 u''(\cdot)}_{<0}\, dG(R) \\
&< 0\,,
\end{aligned}
$$

where

$$
\frac{\partial^2\widetilde{\lambda}(R)}{\partial x^2} = \frac{4\kappa^2(1-\phi_x)^3(1-R)^2}{\sqrt{\left((\kappa(\phi_x-1)+\phi_x(1-x)(1-R))^2 - 4\kappa(1-\phi_x)^2(1-x)(1-R)\right)^3}} > 0\,,
$$

and

$$
\begin{aligned}
\frac{\partial f}{\partial \phi_y} &= \int_0^{1-\kappa} \underbrace{(1-\kappa)u'(\cdot) - (1-\kappa)^2(\phi_y - \phi_x)(1-x)u''(\cdot)}_{>0} dG(R) \\
&+ \int_{1-\kappa}^{\widehat{R}} \underbrace{\left(\frac{R}{1-\phi_y(1-\lambda^*(R))} + \frac{R(1-R)}{\kappa(1-\phi_y(1-\lambda^*(R)))^2}\right) u'(\cdot)}_{>0} \\
&\quad + \underbrace{\left(\frac{(x-\lambda^*(R))(1-R)R^2}{\kappa} + \frac{\kappa(x-1)(1-\lambda^*(R))^2 R}{R-(1-\kappa)}\right) \frac{\phi_y - \phi_x}{(1-\phi_y(1-\lambda^*(R)))^3} u''(\cdot)}_{>0} dG(R) \\
&> 0\,,
\end{aligned}
$$

where $x < \lambda^*(R)$ when $1-\kappa < R < \widehat{R}$. Thus, applying the Implicit Function Theorem immediately shows

$$
\frac{\partial x^*}{\partial \phi_y} = -\frac{\partial f}{\partial x} \cdot \left(\frac{\partial f}{\partial \phi_y}\right)^{-1} > 0\,,
$$

yielding the result. ∎

Proof of Proposition 4. Denote the run threshold as $R' = R(\theta')$, that is, if household i observes a private signal $s_i < \theta'$ she runs; otherwise she stays. Then the population of households who runs, λ, can be written as

$$
\lambda(\theta, \theta') = \begin{cases} 1 & \text{if } \theta \leq \theta' - \varepsilon \\ \dfrac{\theta' - \theta + \varepsilon}{2\varepsilon} & \text{if } \theta' - \varepsilon < \theta \leq \theta' + \varepsilon \\ 0 & \text{if } \theta > \theta' + \varepsilon \end{cases} .
$$

Let $v(R(\theta), \lambda)$ be the difference of utilities between staying and running, then

$$
v(R(\theta), \lambda) = \begin{cases} u\left(\dfrac{x - l_x + yR(\theta)}{1-\lambda}\right) - u(c_1(1-\kappa(\lambda))) & \text{if } 0 \leq \lambda < \dfrac{(1-\phi_x)x}{c_1} \\ u\left(\dfrac{(y-l_y)R(\theta)}{1-\lambda}\right) - u(c_1(1-\kappa(\lambda))) & \text{if } \dfrac{(1-\phi_x)x}{c_1} \leq \lambda < \dfrac{(1-\phi_x)x + (1-\phi_y)y}{c_1} \\ -q(\lambda)\, u(c_1(1-\kappa(\lambda))) & \text{if } \dfrac{(1-\phi_x)x + (1-\phi_y)y}{c_1} < \lambda \leq 1 \end{cases} ,
$$

where l_x solves

$$
\lambda c_1 = x - \phi_x l_x
$$

and l_y solves

$$\lambda c_1 = (1-\phi_x)x + y - \phi_y l_y \,,$$

and $q(\lambda)$ is given by (A.2). If household i observes signal s_i, given that other households use the threshold strategy, she will run if $\int_{s_i-\varepsilon}^{s_i+\varepsilon} v\left(R\left(\theta\right), \lambda\left(\theta, \theta'\right)\right) d\theta > 0$; or stay otherwise.

To prove that there exists a unique run threshold R^*, we need to prove that there is a unique θ^* such that if $\theta' = \theta^*$, the household who observes signal $s_i = \theta' = \theta^*$ is indifferent between run and stay. That is,

$$V\left(\theta^*\right) \equiv \int_{\theta^*-\varepsilon}^{\theta^*+\varepsilon} v\left(R\left(\theta\right), \lambda\left(\theta, \theta^*\right)\right) d\theta = 0.$$

It is easy to check that v is constant on $(0, \theta' - \varepsilon)$, decreasing on $\left(\theta' - \varepsilon, \hat{\theta}\right)$ and increasing on $(\hat{\theta}, 1)$. As θ' increases, the integral of v on $(0, \theta' - \varepsilon)$ remains the same since v does not directly depends on θ in this interval and the length of the interval is constant given ε; on $(\hat{\theta}, \theta' + \varepsilon)$, for any given λ, if θ' goes up, v increases because all θ in this interval goes up. Thus the integral on $(\hat{\theta}, \theta' + \varepsilon)$ increases. In summary, $V\left(\theta'\right)$ is increasing in θ'.

Since $G\left(\cdot\right)$ is supported on $[0, +\infty)$, $R \to +\infty$ when $\theta \to 1$. That is, $\lim_{\theta' \to 1} V\left(\theta'\right) = +\infty$. Furthermore, $V\left(0\right) < 0$. Then by the intermediate value theorem, there exists θ^* such that $V\left(\theta^*\right) = 0$. The uniqueness of θ^* follows by the monotonicity of $V\left(\cdot\right)$ and so does R^*.

Finally, notice that given the unique run threshold R^*, there must be $l_x^*(R) = l_y^*(R) = 0$ when $R > R^*$ while $l_x^*(R) = x$ and $l_y^*(R) = y$ when $0 \leq R < R^*$, and therefore reverse flight to liquidity never happens. ∎