Mutual Fund Liquidity Transformation and Reverse Flight to Liquidity*

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Abstract

We identify fixed-income mutual funds as an important contributor to the unusually high selling pressures in traditionally liquid asset markets during the Covid-19 crisis. We show that fund liquidity transformation lead to pronounced investor outflows. In meeting redemptions, funds followed a pecking order by first selling their more liquid assets, which generated the most concentrated selling pressures in traditionally *more liquid* asset markets. Investors' flight to liquidity was thereby turned into an aggregate *reverse flight to liquidity*. The Fed's announced purchase of illiquid securities may be an effective 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 over companies' credit quality caused a scramble amongst investors to reduce their exposure to illiquid corporate debt. However, the impact was not limited to illiquid 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.

The pronounced pressure to sell traditionally assets is surprising in light of the flight to liquidity phenomenon generally seen in crises, which would suggest a pronounced demand to *buy* high-quality liquid assets. In the 2008 financial crisis, Treasury yields fell on days of market distress, whereas during the Covid-19 crisis, this relationship is reversed (see Figure 3 and also Fleming and Ruela (2020) and He, Nagel, and Song (2020)). These selling pressures were substantial and cannot be explained by sovereign default risk and inflation expectations (Figure 4). Large selling pressures were also present in the most liquid segments of the corporate bond market, where the CDS-bond basis of investment-grade bonds at times reached the CDS-bond basis of high-yield bonds (see Figure 5 and also Haddad, Moreira, and Muir (2020)).

The puzzling price movements in traditionally liquid asset markets sparked a fast growing body of research. Most existing work has focuses on the dealer side, explaining why dealers did not more forcefully lean against the wind (Duffie, 2020, He, Nagel, and Song, 2020, Kargar, Lester, Lindsay, Liu, Weill and Zuniga, 2020, O'Hara and Zhou, 2020). However, the origins of the selling pressure are equally important to understand. Why was there such pronounced selling pressure? And why were they concentrated in some of the traditionally most liquid asset markets?

In this paper, we provide a novel explanation for the reverse flight to liquidity phenomenon by tracing a large share of the selling pressure to fixed-income mutual funds. We find that fixed-income mutual funds suffered unprecedented outflows in March 2020 because of the fragilities induced by their transformation of illiquid assets into demandable fund shares (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. This is why the pronounced outflows generated concentrated selling pressure in traditionally liquid asset markets. Investors' flight to liquidity was thus turned into an aggregate *reverse flight to liquidity*. In aggregate, the mutual fund sector sold off \$236 billions in Treasuries in the first quarter of 2020 — the highest amongst financial institution— and contributed to the large price discounts in Treasury markets. Similarly, highly-rated corporate bond also rank high in the pecking order of liquidation and were sold off in large volumes, which contributed to strains in secondary bond markets.

Fixed-income mutual funds' illiquidity-induced outflows coupled with the their liquidation policies expose traditionally-liquid asset markets to acute and systematic sell-offs, which could disrupt key functions that liquid asset markets provide for the financial system. Similar liquidity events are likely to reoccur because of the increasing role of fixed-income mutual funds in liquidity transformation. Their assets under management have expanded from less than \$1.5 trillion in 2007 to 4.5 trillion in 2019 (Figure 1). This trend is unlikely to reverse itself. Tracing out the behavior of bond funds during the Covid-19 crisis, which presents the first stress test for the fixed-income mutual fund sector since its newly gained prominence, is thus essential for understanding the implications of mutual fund liquidity transformation on asset markets going forward.

Our findings also bear important policy implications. Traditionally, the Federal Reserve has been limited to purchasing relatively safe assets such as Treasuries. The unprecedented expansion into purchasing corporate bonds during the Covid-19 crisis raises important questions regarding the role of similar policy tools going forward. We show that the announcement of purchasing illiquid bonds significantly alleviated fund outflows. 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 and liquid asset markets.

To arrive at our results, we first provide aggregate evidence that 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 were much smaller at equity funds, which is suggestive of asset illiquidity being an important amplifier of outflows. Within the fixed-income fund sector, funds specializing in more illiquid asset classes such as bank loan funds and high yield corporate bond funds also experienced larger outflows than investment grade and government bond funds, which again points to the important role of liquidity transformation in driving fund outflows. Although outflows at illiquid funds were larger, it was the most liquid assets in their portfolios such as Treasuries and high-quality corporate bonds that were disproportionately sold, which is in line with the large selling pressures observed in these markets.

We develop a simple conceptual framework to shed light on the economic mechanisms at play. In the model, which we detail in the appendix, mutual funds transform liquidity by optimally holding a portfolio of illiquid asset such as high-yield bonds, together with liquid asset such as Treasuries as liquid buffers. When economic fundamentals deteriorate, investors' redemption requests increase. Investors' have a higher incentive to redeem when mutual funds transform more illiquid assets into liquid shares because those who remain in the fund will have to bear a larger proportion of the liquidation costs. In meeting redemptions, the fund chooses to first sell the more liquid asset before tapping into the illiquid asset that incurs a higher liquidation cost. This leads to more concentrated sales in the more liquid asset when economic fundamentals deteriorate, i.e. reverse flight to liquidity, which is more severe in funds transforming more liquidity.

We provide micro-level evidence to confirm the intricate relationship between fund liquidity transformation and the reverse flight to liquidity phenomenon during the Covid-19 crisis in three steps. 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 also amongst the highest across all other observable fund characteristics.

In the second step, we verify which securities were more likely to be sold in meeting investor redemptions. We first estimate the liquidation to outflow sensitivity by regressing bond-fund level liquidations against outflows at their corresponding funds in March 2020. We find that more liquid corporate bonds and Treasury securities have higher liquidation to outflow sensitivities than less liquid corporate bonds.[1] These findings are consistent with funds following a pecking order to meet redemption requests in March 2020.

The pecking order of liquidation implies that the likelihood for a fund to sell a given bond not only depends on the liquidity of that bond but also on the relative liquidity of the fund's other assets. For example, an investment grade bond held by a high yield fund could be amongst the first assets to be sold while the same bond held by an investment grade fund may come much later in the pecking order. To capture the relative liquidity of bond within a fund's portfolio, we

[1] We use bond ratings as a proxy for bond liquidity and confirm that bond ratings decrease with standard measures of illiquidity (see Figure 11)

define liquidation rank for a bond in a fund's portfolio as the share of more liquid bonds held by the same fund.[2]

We find that a bond ranked at the bottom of the pecking order of actively managed funds (i.e liquidation rank of 0) has a liquidation to outflow sensitivity of 0.21, whereas the same bond at the top of the pecking order (i.e. liquidation rank of 1) has a liquidation to outflow sensitivity of 0.59. This confirms the presence of and captures the extent to which actively managed funds follow the pecking order. For bonds held by index funds, the difference in liquidation to outflow sensitivities between liquid and illiquid bonds is economically smaller and statistically insignificant, showing that their passive nature constrains the use of the pecking order. Note that our results are not driven by bond-specific differences because we compare the effect of liquidation rank on liquidation to outflow sensitivities for the same bond.

In the third step, we show that pronounced fund outflows contributed to the price pressure observd in fixed income markets during the Covid-19 crisis. We first examine the effect of fund outflows on bond returns by regressing daily bond returns on imputed outflows for the same bond. We calculate daily imputed outflows as the weighted average of daily outflows at funds holding the bond as of 2019Q4, where weights are given by the volume of funds' holdings. We find that imputed outflows depress bond returns with economic and statistical significance. We ensure that our results can be interpreted as outflows-induced price pressue by removing time-varying common exposures at the issuer, rating, and maturity-bucket level.

To pinpoint the joint effects of fund outflows and fund liquidation policies on asset prices, we develop a novel measure of liquidation-adjusted outflow (LAO) that incorporates the empirical pecking order of liquidations into imputed outflows. The LAO is calculated in two steps. First, we adjust daily bond-fund outflows by multipling daily fund-level outflows by the estimated liquidation to outflow sensitivity corresponding to the liquidation rank of the bond. Then, we average the adjusted outflows at the bond-level weighing by the volume of fund's holdings. If the pecking order applies, the LAO should be more effective than imputed outflows at capturing price impact by mutual funds because it considers how likely outflows are converted into actual liquidations. Indeed, a 1% increase in LAO corresponds to a 3.98 basis point drop in bond

[2]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 liquidation rank for each of the Treasury notes would be 0.9 and the liquidation rank for each of the AAA-rated corporate bonds would be 0.7.

returns, which is more than double than that for a 1% increase in imputed outflows, controlling for time-varying shocks at the issuer maturity, and rating level.

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 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 on April 9 had the largest impact on alleviating fund outflows and costly asset liquidations compared to other interventions like the purchase of Treasury securities.

If the announcement of Fed interventions were effective at easing asset market strains through reducing fund outflows and the subsequent asset liquidations, then it should be those bonds that were more likely to be sold by funds that benefit the most in terms of returns. Indeed, for bonds issued by the same firm, of the same rating, and in the same maturity bucket, those with an above-median liquidation rank experienced a 10.9 basis point larger increase in returns than those with a below-median liquidation rank following the April 9 announcement, which confirms our conjecture.

Through the lens of our model, the announcement of future bond purchases improves expectations about fund asset returns, and thereby curbs the immediate fund outflows. In contrast, 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 financial markets as liquidity transformation is increasingly migrating beyond the commercial banking sector.

Related Literature. We show that the increased reliance on liquidity transformation by mutual funds turned investors' flight to liquidity into an aggregate reverse flight to liquidity. We thus contribute to the understanding of the liquidity events in financial markets during the Covid-19 crisis.

A number of studies have documented the systematic disrutpions in debt markets. Fleming and Ruela (2020) first document the unusual drop in liquidity and increase in volatility in Treasury markets, and Haddad, Moreira, and Muir (2020) identify strains in high-quality segments of corporate bonds and bond ETFs. Chen, Liu, Sarkar and Song (2020) find similar strains in mortgage-backed securities markets. Liang (2020) and Vissing-Jorgensen (2020) provide reviews on the debt market developments and provide additional insights about the potential mechanisms.

In explaining the debt market disruptions, Duffie (2020) and He, Nagel, and Song (2020) 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 corporate bond illiquidity. We analyze a complementary channel by identifying fixed-income mutual funds as a dominant seller of liquid assets. Our focus on the patterns of fund asset liquidation their corresponding asset pricing implications also complements Falato, Goldstein and Hortacsu (2020), who examine various sources of fragility in fund flows. Schrimpf, Shin and Sushko (2020) point to hedge funds as a another source of selling pressures in Treasury markets.

More generally, we also contribute to the literature on mutual fund flows and their financial stability implications. Chen, Goldstein and Jiang (2010) and Goldstein, Jiang and Ng (2017) find that the flow-to-performance relationship is more concave for more illiquid funds. We focus on mutual fund liquidity transformation and demonstrate the consequences on asset markets as their 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 (2020) and Jiang, Li and Wang (2020), who find limited price impact by mutual fund outflows on illiquid asset markets. 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 paper further adds to the large literature examining the price impact of mutual fund-flow driven trading (Coval and Stafford, 2007, Frazzini and Lamont, 2008, Lou, 2012). We develop a novel liquidation-adjusted outflow (LAO) measure, which incorporates the empirically observed liquidation policy of mutual funds into the imputation of outflows. This methodological innovation allows us to pinpoint both the flow-driven and the liquidation-policy-driven aspect of mutual funds' effect on asset prices. We believe that our measure may be useful for future studies exploring the asset pricing implications of mutual funds.

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 explores fund-level and bond-level variation to show how mutual fund liquidity transformation contributed to the recent reverse flight to liquidity phenomenon. Section 4 examines interventions by the Federal Reserve and its effects on mutual fund flows and NAVs. We discuss our results in the context of a simple theoretical framework, which we detail in Appendix A.

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. 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 (see also He et al. (2020)). 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 risk 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 the presence of 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. Corporate bonds markets also experienced liquidity strains well beyond what fundamentals can explain. 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 a large part of the selling pressure cannot be accounted for by corporate default risks. In particular, Figure 5 shows that the widening of the CDS-bond basis during the Covid-19 crisis became particularly pronounced for the relatively more liquid investment-grade bonds than the less liquid high-yield bonds.

Taken together, concentrated 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 their riskier and more illiquid assets such has high-yield corporate bonds. As we will show, the selling pressure for Treasuries and high-quality corporate bonds during the Covid-19 crisis are intricately related because both are held as liquid asset buffers by fiexed-income 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. Pastor and Vorsatz (2020) find that "the [active equity fund] outflows are faster than their long-term trends, but the difference is not dramatic" (Page 4). The difference in outflows between equity and fixed-income 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 more-illiquid assets would suggest the sale of more illiquid assets. Rather, we find that fixed-income funds disproportionately sold the most liquid components of their portfolios to pay redeeming investors. Figure 7 plots the percentage change in holdings of different fixed income securities sorted by liquidity. We use ratings to proxy for the liquidity of corporate bonds, where higher rated bonds are generally more liquid than lower rated ones. In section 3.1 we confirm this assumption using a set of standard liquidity measures. 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.

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. The proportion of Treasuries held by mutual funds experienced the largest decline at 18% in 2020Q1.[3]

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 first describe the data. Then, we begin by demonstrating that funds transforming more liquidity also suffered higher outflows during the Covid-19 crisis. We further show that funds displayed a pattern of first selling more liquid assets

[3]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.

in meeting outflows . 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 use the CRSP Mutual Fund Database to create a sample of US open-end fixed-income mutual funds. For each fund, we observe its monthly flows, portfolio returns, assets under management, and quarter-end securities holdings. We complement the CRSP database with the daily fund flows and NAV information from Morningstar database. Our sample contains 6,356 unique share classes and 1,942 funds.

Table 2 presents summary statistics of the mutual fund sample as of March 2020. The average return in March is -5.8%. The average outflows are 2.55% with a large cross-section dispersion: the outflows at the 90th percentile reaches 12.7%.

We construct two measures of fund liquidity transformation. The first measure is asset illiquidity, which is calculated based on the weighted average of haircuts for the fund's assets. Funds' portfolio holdings are as of December 31, 2019 and repo haircuts by asset category are obtained from the New York Federal Reserve. The average asset illiquidity is 4.6% and the standard deviation is 1.1%. The second measure is the Liquidity Provision Index (LPI), which measures how much more investors expect to obtain by redeeming $1 of shares from a fund compared to directly selling the underlying portfolio of assets (Ma, Xiao and Zeng, 2019). The average LPI of our sample funds is 4.2% and the standard deviation is 1.0%.

To control for the credit risks of the funds, we construct return volatility using the monthly return from 2015 to 2019. The average return volatility is 0.73%. The average income yield is 0.48%. The average maturity of the portfolio holdings is 11 years. The average expense ratio is 0.85% and the average turnover ratio is 1.0%.

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 assign corporate bonds and Treasuries into liquidity-groups. Treasuries are in the first group, while subsequent groups are defined by the ratings of corporate bonds. That is, AAA-rated corporate bonds are in group two, AA+ rated corporate bonds are in group three, etc. We confirm that standard measures of bond illiquidity in the literature, including Amihud, Roll, and Imputed Round-trip Costs (IRC), are increasing in our ratings-based liquidity-group measure (see Figure 11. We adopt this approach over specific bond-level illiquidity measures because the latter could only be constructed for bonds with actual transactions whereas the former is more readily available for bonds held in funds portfolios but without recent transactions.

Nevertheless, we recognize that corporate bond ratings also capture credit risk. To this end, we will perform a number of tests with bond-fund level liquidity measures and control for issuer-time fixed effects, rating-time fixed effects, and maturity-time fixed effects. These results will be robust to time-varying credit risk at the issuer and ratings level.

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. We argue that these outflows are intricately tied to fixed-income mutual funds' liquidity transformation. On the liability side, bond mutual funds issue demandable shares that investors can redeem for cash at short notice. At the same time, their assets are increasingly invested in long-term and illiquid debt securities like corporate bonds and loans that incur large liquidation discounts when sold before maturity and that are difficult to price given low market liquidity. In recent years. bond mutual funds have become an important provider of liquiditity transformation in the economy (Chernenko and Sunderam, 2017, Ma, Xiao and Zeng, 2019)

We formulate the consequence of mutual fund liquidity transformation in a model detailed in Appendix A. In our framework, investors redeem shares when their prospects about the long-term economic fundamentals decline (Proposition 1), generating fundamental-driven outflows. These outflows are larger at more illiquid funds (Proposition 2). Intuitively, when investors redeem shares from a fund, the fund prematurely liquidates assets at a cost to meet their redemption requests. With stickiness in the adjustemt of funds' net asset values (NAVs), not all the costs from premature asset liquidations will be incorporated in the end-of-day NAV and some 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 fund assets are more illiquid and fund NAV is more sticky, leading to more pronounced outflows. This intuition is consistent with earlier work that highlights potential strategic complementarities between mutual fund shareholders, which finds a stronger flow-to-past-performance relationship in less liquid equity funds (Chen, Goldstein and Jiang, 2010) and a concave flow-to-past-performance relationship in bond funds (Goldstein, Jiang and Ng, 2017).

We proceed to analyze the relationship between fund liquidity transformation and fund outflows in the data. Our first proxy for fund liquidity transformation is the average illiquidity of their asset portfolio. We measure fund asset illiquidity using the weighted average of haircuts incurred by $1 invested in the fund's portfolio. Intuitively, when assets are more illiquid, haircuts are higher so that less cash can be raised against them.[4] The upper panel of Figure 9 shows a binned-scatter plot of fund outflows in March 2020 against their respective asset illiquidity in 2019Q4. The clearly positive relationship between the two variables suggests that fund 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 fund liquidity transformation using the Liquidity Provision Index (LPI). Intuitively, the LPI captures how much more can be obtained by redeeming $1 of fund sharesrelative to the direct liquidation value of the underlying assets.[5] The more liquidity is transformed by a fund, the higher its LPI. We repeat the same binned-scatter plot of outflows against fund LPI. The results shown in the lower panel of Figure 9 suggest that higher fund liquidity transformation in 2019Q4 came at the expense of larger outflows in March 2020.

Recognizing that funds may differ along dimensions other than their liquidity transformation, we repeat our analysis while holding a range of fund characteristics constant. Specifically, we regress cumulative outflows for fund j in March 2020 against its asset illiquidity and control for fund characteristics including volatility, return, yield, expense ratio, and turnover ratio in 2019Q4

[4]Although funds do no directly trade in repo markets, repo haircuts can be seen as a proxy for illiquidity in general.

[5]Please refer to Appendix ? for details on the construction of the LPI.

(see equation (3.1)). We denote the vector of fund-level controls with X_j. We also include a fixed effect $\theta_{o(j)}$ for different investment objectives $o(j)$ so our results should be interpreted as a within fund-type effect that absorbs differences in fundamentals across asset classes. We present the results in Table 3.

$$\text{Outflows}_j = \beta \text{Asset Illiquidity}_j + \gamma \mathrm{X}_j + \theta_{o(j)} + \epsilon_j. \tag{3.1}$$

From the result in Table 3, we see that the coefficient on asset illiquidity remains significant at the 1% level regardless of how the model is saturated with controls and fixed effects. The fit of the model is also only minimally improved with the addition of explanatory variables. Magnitude wise, when asset illiquidity increases by one standard deviation, fund outflows are 0.6% higher in March 2020 in the most restrictive specification in column 4.

$$\text{Outflows}_j = \beta \text{LPI}_j + \gamma \mathrm{X}_j + \theta_{o(j)} + \epsilon_j. \tag{3.2}$$

We repeat the same specification with fund LPI in place of fund illiquidity (equation (3.2)). The results in Table 4 are consistent with fund liquidity provision leading to higher outflows in March 2020. In particular, when fund LPI increases by one standard deviation, outflows increase by 0.824% in the most restrictive specification in column 4. This effect is economically important. In comparison, a one standard deviation increase in volatility increases outflows by 0.819%, while a one standard deviation drop in expense ratio and turnover ratio are correlated with 0.183% and 0.537% higher outflows. Taken together, these results confirm that higher fund liquidity transformation contributed to larger fund outflows during the Covid-19 crisis.

Taken together, we show that mutual fund liquidity transformation contributed to the unprecedentedly large fund outflows during the Covid-19 crisis. These findings are consistent with Falato, Goldstein and Hortacsu (2020), who find similar patterns and who further decompose the factors that contributed to outflows from funds during the Covid-19 crisis. We focus on the asset liquidations and asset pricing implications stemming from mutual fund outflows, which we explore in the next two subsections.

3.3 Pecking Order of Liquidation

Pronounced outflows alone cannot explain why selling pressure emerged in the traditionally most liquid asset markets during the Covid-19 crisis. Funds' strategies on which assets to liquidate also played a vital role. Our model shows that when the fundamental shock is large but short-lived, the optimal strategy in meeting redemption requests is to sell more-liquid assets before more-illiquid ones (Proposition 1), consistent with the view of liquidating liquid assets first to minimize price impact (Scholes , 2000). We believe that the nature of a one-off shock to expected economic fundamentals captured in our model matches the context of the Covid-19 crisis well, which posed an unexpected and acute shock to firms' cashflows and hence the expected performance of their debt securities that are held by bond mutual funds.

We first examine how the sensitivity of liquidations for a given bond varies with respect to outflows at funds holding that bond. The pecking order of liquidations would suggest a higher sensitivity for more liquid securities. To check, we regress liquidations of bond i by fund j on the outflows at fund j for Treasuries and corporate bonds of different liquidity groups $g(i)$ as in equation (3.3).[6] Bond-fund level liquidations and fund-level outflows are measured as their respective percentage changes from the end of February to the end of March. We also control for fund and bond level characteristics $X_{i,j}$ including maturity, lag fund size, and fund returns. We plot the coefficients on the main explanatory variable, fund outflows, in Figure 10. The capped bars represent the 95% confidence interval of the point estimates.

$$\text{Liquidation}_{i,j} = \beta_{g(i)}\text{Outflows}_j + \gamma_{g(i)}\text{X}_{i,j} + \theta_{o(j)} + \epsilon_{i,j}. \tag{3.3}$$

From Figure 10, we observe a larger liquidations to outflow sensitivities for more liquid bond-types. This implies that more liquid bonds are sold off by a larger extent following fund outflows. The point estimate of the liquidation to outflow sensitivity for Treasuries is above that of all corporate bonds except the ones in in liquidity-group two, i.e. the AAA rates ones. Nevertheless, the statistical significance of the difference is limited as suggested by the wide confidence interval for AAA rates corporate bonds. Overall, the positive relationship between liquidations to outflow sensitivities and bond liquidity is consistent with a pecking order of liquidations in which more liquid assets are sold first. At the same time, the trend rules out

[6] Recall from section 3.1 that Treasuries have a liquidity group of one, which is then followed by corporate bonds with increasing ratings.

that only a credit-risk channel was at play, which would suggest a larger tendency to sell riskier bonds from funds' portfolios.

Our results imply that reverse flight to liquidity is not necessarily confined to the most liquid assets. Instead, it is a continuous phenomenon whereby as fundamentals deteriorate, relatively more liquid securities in the portfolio are sold before less liquid ones. By the same token, as fundamentals deteriorate, more liquid tranches of the portfolio experience heightened selling pressure before relatively less liquid tranches. During the Covid-19 crisis, 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 allowed 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 as well.

So far, we have estimated the propensity of liquidation based on the absolute level of liquidity of a given bond. In reality, the likelihood of liquidating a bond at a given fund not only varies with the liquidity of the bond itself but also with the relative liquidity of the fund's other assets. For example, an investment grade bond held by a high-yield fund could be part of the first assets to be sold, while the same investment grade bond held by a fund with predominantly investment grade assets may come much later in the pecking order.

To capture the relative liquidity of bonds within a fund's porfolio, we define a liquidation rank at the bond-fund level. Specifically, the liquidation rank of a bond in a given fund 's portfolio is the share of other bonds held by the same fund that are less liquid. Since bond-level liquidation discounts are difficult to measure accurately, we sort by the liquidity-group of bonds. As before, Treasuries are ranked before corporate bonds in decreasing ratings. We further split Treasuries into Treasury bills, Treasury notes, and Treasury notes. For all securities within each bond category, we take the mid-point within the category as liquidation rank. 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 liquidation rank for each of the Treasury notes would be 0.9 and the liquidation rank for each of the AAA-rated corporate bonds would be 0.7. A higher liquidation rank thus indicates a more liquid bond within a fund's portfolio. Formally, we define the liquidation rank of bond i in fund j that belongs to liquidity category $l(i)$ as

$$\text{Liquidation Rank}_{i,j} \doteq \sum_{g(i')} \text{Share}_{g(i'),j} \times \mathbb{1}\left[\text{Liq. Group}_{g(i)} > \text{Liq.Group}_{g(i')}\right] + \frac{1}{2}\text{Share}_{g(i),j}, \quad (3.4)$$

where $\text{Share}_{g(i'),j}$ is the share of bonds i' in the liquidity-group $g(i')$ in fund j's portfolio.

Then, we consider how the liquidation rank affects bonds' liquidation to outflow sensitivity. We regress the percentage liquidation of each bond i at fund j in March 2020 against fund j's outflows in March 2020 interacted with the liquidation rank of bond i in fund j as of the end of February (see equation (3.5)). We run separate specifications for active open-end funds and passive open-end funds because the investment mandate of the latter may interact with the pecking order. We also include fixed effects for fund objective $\theta_{o(j)}$ and bond-level fixed effects δ_i to ensure that our results are not driven by bond-specific or fund-type specific differences. Table 5 details the results.

$$\text{Liquidation}_{i,j} = b_0 \, \text{Outflows}_j + b_1 \, \text{Outflows}_j \times \text{ Liquidation Rank}_{i,j} + \theta_{o(j)} + \delta_i + \epsilon_{i,j}. \quad (3.5)$$

From the results in Table 5, we see that the coefficient on the interaction between outflows and rank is statistically significant for activeley managed mutual funds. This implies that when the same bond is ranked higher in the pecking order of one fund relative to another fund, it also has a higher tendency to be sold when there are fund outflows, consistent with the pecking order of liquidations. Note that this effect is not driven by credit risk or other unobserved features at the bond-level because we are comparing liquidation to outflow sensitivities using within-bond variation. The magnitude is economically important. The estimates in column (2) suggest that the same bond ranked at the bottom of the pecking order with a liquidation rank of 0 is liquidated by 0.21% for a 1% outflow while the same bond at the top of the pecking order with a liquidation rank of 1 would have been liquidated by 0.59% for the same 1% outflow.

In contrast, the coefficient on the interaction term for open-end index funds in column (3) of Table 5 is not significant. This suggests that for index mutual funds, the liquidation rank of bonds does not affect their liquidation to outflow sensitivity in a statistically significant way. Moreover, the economic magnitude of the point estimate is 0.082, which is much smaller than that for actively managed mutual funds. These findings suggest that index mutual funds appear to liquidate their portfolios proportionally instead of following the pecking order of liquidation, consistent with constraints by their mandate to track bond indeces.

Taken together, our results indicate that when not constrained by their investment mandate, bond mutual funds liquidated more-liquid assets first to meet redemption requests during the Covid-19 crisis. This finding can be also reconciled with recent work that shows the optimality of pecking-ordered liquidation when the shock is one-off but argues that liquidating more-illiquid assets first may be optimal when the shocks are expected to be persistent and the option value of liquidity-hoarding is accordingly high (e.g., Brown, Carlin and Lobo, 2010, Morris, Shim and Shin, 2017, Jiang, Li and Wang, 2020). Indeed, the shocks were largely perceived as unexpected and short-lived at the onset of the Covid-19 crisis, likely lowering the perceived option value of liquidity-hoarding and thus rationalizing the observed liquidation policies of mutual funds.

3.4 Reverse Flight to Liquidity and Asset Prices

Section 2 has shown that mutual funds' outflows and asset sales occur around the same time as liquid asset prices fell. Nevertheless, it remains to be shown whether mutual funds' reverse flight to liquidity indeed contributed to the price inpact. In this section, we examine how bond-level returns vary with the outflow at funds who held the bond and their respective liquidations ranks in the funds' portfolios.

We begin by showing that in aggregate, bonds with higher liquidations ranks in funds' portfolios experience larger drops in prices during the Covid-19 crisis. We first define and calculate a bond-level liquidation rank by averaging across the bond-fund level liquidation ranks at all funds j that held bond i in 2019Q4 weighted by the size of holdings:

$$\text{Liquidation Rank}_i \doteq \sum_j \text{Liquidation Rank}_{i,j} \times \frac{\text{Holding}_{i,j,2019Q4}}{\sum_k \text{Holding}_{i,k,2019Q4}}, \tag{3.6}$$

where Liquidation $\text{Rank}_{i,j}$ is given by (3.4).

Then, we group bonds by quartiles of their liquidation rank in 2019Q4, demean their bond yields by rating-date fixed effects to purge out the changes in credit risk, and plot the demeaned yields by liquidation rank quartiles in Figure 12. For easier comparison, the yields at the beginning of February 2020 are normalized to zero.

Figure 12 shows that for bonds of the same rating, higher-ranked ones in the liquidation order of funds' portfolios experienced larger price drops and larger yield increases than those lower in the liquidation order during the Covid-19 crisis. This variation suggests that the higher selling pressure for bonds higher up in the pecking order trickled down to impact overall asset prices.

Notice also that the divergence in yields across the liquidation rank quartiles starts at the beginning of March 2020 and widens until the end of March. In our framework, this is because the notion of liquidation rank only materializes into actual liquidations when there are actual outflows. Recall from Figure 6 that bond fund outflows were indeed most pronounced during this time period.

We proceed with examining the effect of fund outflows on the returns of the bonds in their portfolio. If mutual funds' reverse flight to liquidity affected asset prices, we would expect that bonds held by funds with larger outflows also suffered larger drops in returns becaue they are more likely to be sold relative to bonds at funds with less pronounced outflows. To this end, we construct an imputed outflow measure similar to Lou (2012). For each bond i, we take a weighted average of outflows at funds j that held this bond at the end of 2019Q4, where weights are defined by the volume of funds' holdings of bond i. Formally, the imputed outflow of bond i at date t is given by

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

Then, we regress daily bond-level returns against their daily imputed outflows from Jan 1, 2020 to March 31, 2020 as in equation (3.7) below.

$$\text{Return}_{i,t} = \beta \text{Imputed Outflow}_{i,t} + \gamma \text{X}_{i,t} + \delta_i + \kappa_{f(i),t} + \tau_{m(i),t} + \omega_{r(i),t} + \epsilon_{i,t}. \tag{3.7}$$

The intended interpretation of the coefficient β is the impact on bond returns by outflows at funds holding the bond in question. Nevertheless, there could be other shocks that affect both bond returns as well as investors' redemptions at funds holding the bond in question. During the Covid-19 crisis for example, different sectors of the economy were heterogeneously exposed, which could affect both the returns of bonds issued by these sectors and the outflows at funds holdings their bonds. To alleviate this concern, we include, in our most restrictive specification, fixed effects for issuer-time $\kappa_{f(i),t}$, ratings-time $\omega_{r(i),t}$, and maturity-time $\tau_{m(i),t}$, where maturity is defined as yearly buckets of the bond's remaining maturity. Effectively, this removes any time-varying common exposures (e.g. credit risk fluctuations) to both bond returns at the issuer, rating and maturity-bucket level so that the variation remaining in β most likely represents the effect of fund outflows on bond returns.

One remaining concern is if fund outtflows are correlated with other types of investor flows in bond markets that determined the variation in returns. While we do not observe all bond market investors and cannot conduct an exhaustive check, there are a few reasons why this is unlikely to be the case. First, any such behavior must be confined to within bonds issued by the same issuer and of the same maturity bucket and rating. Second, they would have to correlate with imputed outflows which involves both fund-level outflows as well as the weights by funds' holding size. Finally, we directly account for outflows at fixed income exchange traded funds (ETFs). While bond ETFs operate under a different technology than open-end mutual funds, they also invest in illiquid fixed income securities and are likely to affect pricing of the same set of securities. Specifically, we control for the daily outflows from fixed-income ETFs that hold bond i as of 2019Q4 in all specifications.

The results from estimating equation (3.7) are presented in column 4 of Table 6. Columns 1 to 3 in the same table repeat the estimation with different sets of fixed effects. The coefficient on impputed outflows is negative and statistically significant at the 5% level across all four specifications. The economic magnitudes are also similar. In the most restrictive specifiction in column 4, a 1% increase in imputed outflows is linked to a -1.74 basis point decrease in yields at bonds issued by the same issuer and of the same rating and maturity bucket. This magnitude is likely a lower bound of the total impact of fund outflows on bond returns because any aggregate effects of fund outflows on returns at the issuer, rating, and maturity level are removed. Nevertheless, the power of fund outflows in affecting returns of bonds that share the same issuer, rating, and maturity reassures us that our findings are indeed driven by outflows at bond mutual funds. Further note that these magnittudes are the effect of fund outflows on bond returns and not yet the direct effect of fund liquidations on bond returns, which we will proceed to examine next.

While the results in Table 6 show that imputed outflows trickle down to affect bond returns, they do not factor in the empirical liquidation policy at funds. Recall from Section 3.3 that bonds ranked higher in the order of liquidations are disproportinately sold following fund outflows at active funds, i.e., the pecking order of liquidation applies. At the same time, Figure 12 implies that bonds with higher liquidation ranks experienced larger price drops in March 2020. Taken together, these results suggest that incorporating the empirical liquidation policy into imputed outflows could be a more accurate way to capture the price impact of mutual funds' reverse flight to liquidity.

To this end, we propose the Liquidation-Adjusted Outflow (LAO) as a novel measure that incorporates the empirical pecking order within funds' portfolio.[7] It is also a bond-level measure similar to imputed outflows. However, rather than taking the weighted average over fund-level outflows at funds, LAO takes the weighted average over bond-fund level adjusted outflows that incorporate the funds' empirical liquidation policy. Bond-fund level adjusted outflows for bond i held by fund j at time t captures outflows at fund j that apply specifically to the liquidation rank of bond i. The adjustment applies the empirical liquidation policy estimates from Table 5. Specifically, we define LAO for bond i at time t is defined as

$$\begin{aligned}&\text{Liquidation-adjusted outflow (LAO)}_{i,t}\\ &\doteq \sum_j \text{Fund outflow}_{j,t} \times (\hat{b}_0 + \hat{b}_1 \,\text{Liquidation Rank}_{i,j}) \times \frac{\text{Holding}_{i,j,2019Q4}}{\sum_k \text{Holding}_{i,k,2019Q4}}.\end{aligned} \tag{3.8}$$

where $\hat{b}_0$ and $\hat{b}_1$ are the coefficients in equation (3.5) reported in Table 5.

Compared with existing measures in the literature, the benefit of the LAO is to accounts for the differential selling pressure of outflows on bonds according to their rank in funds' empirical liquidation policy. For example, two bonds held by the same funds will have the same imputed outflows but their LAOs will vary with their liquidation rank within the fund. If the pecking order of liquidations applies and asset sales by bond funds trickle down to asset prices, then bonds higher up in the pecking order of liquidations are more likely to be sold and the LAO would reflect the price impact of bond funds' outflow-induced asset liquidations more accurately. In this case, we would expect bond returns to respond more to the LAO relative to the unadjusted imputed outflows.

To test the above conjecture, we re-estimate specification (3.7) by replacing imputed outflows with the Liquidation-Adjusted Outflow (LAO) while keeping the same set of controls and fixed

[7] We thank Stefan Nagel for helpful comments and suggestions that inspired the construction of the LAO.

effects:

$$\text{Return}_{i,t} = \beta\text{Liquidation-Adjusted Outflow}_{i,t} + \gamma \text{X}_{i,t} + \delta_i + \kappa_{f(i),t} + \tau_{m(i),t} + \omega_{r(i),t} + \epsilon_{i,t}. \quad (3.9)$$

The results from estimating equation (3.9) are displayed in Table 7. Observe that in all four columns, the coefficient on LAO is negative and statistically significant. The magnitude of the coefficient are also larger than the corresponding coefficients on imputed outflow in Table 6. For the most restrictive specification in column 4 for example, a 1% percent increase in the LAO corresponds to a 3.98 basis point drop in bond returns, which is more than double than that for a 1% increase in imputed outflows. As before, this result is obtained by comparing bonds with the same issuer, maturity, and rating so that credit risk and other confounding factors are unlikely determinants. Rather, it is the liquidation adjustment to outflows that better captured the price impact of mutual funds' reverse flight to liquidity by incorporating the pecking order of liquidations at the bond-fund level.

Compared to the findings in Choi, Hoseinzade, Shin and Tehranian (2020), who find little evidence for fire-sale price impact by bond mutual funds over the sample period from 2005 to 2014, our results in this section likely arise for a number of reasons. First, the acute and systematic Covid-19 shock triggered outflows large enough to generate the sale of bond securities, including Treasuries and liquid corporate bonds. At the same time, the fixed-income mutual fund sector has rapidly grown in size and increasingly invested in illiquid assets over the last decade years, which lead to a larger liquidity buffer in the form of traditionally liquid assets to begin with. The systematic depletion of this liquid buffer during Covid-19 then spilled over to affect aggregate asset prices. Going forward, as mutual funds ineasingly engage in more liquidity transformation, we expect them to further increase their holdings of traditionally liquid assets as liquid buffers (Proposition 3). Therefore, future mutual fund-induced strains in asset markets are likely to reemerge in the future.

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 bonds purchases. 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 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 rated investment grade as of March 22.

A growing body of work has also examined the effect of Fed interventions on debt markets (e.g., Boyarchenko, Kovner and Schachar, 2020, Haddad, Moreira, and Muir, 2020, Kargar, Lester, Lindsay, Liu, Weill and Zuniga, 2020, O'Hara and Zhou, 2020). These studies focus on different channels such as bond eligibility and dealer constraints to explain the impact of different policy announcements. We complement their findings and pinpoint a novel transmission channel of the Fed interventions: alleviating asset market strains through curbing mutual fund outflows. As we will explain, the mechnanism we suggest is consistent with the large announcement effect relative to the implementation effect of these policies.

4.1 Announcement Effect on Fund Outflows

We first evaluate the impact of the various policy announcements on fund-level flows. We regress daily fund outflows on indicator variables for each intervention. To ensure that the coefficients capture the intended announcement effect, we control for the trajectory of the pandemic using the growth rate of infections X_t, include fund fixed effects θ_j to remove fund-level heterogeneities, and absorb time trends using month fixed effects $\nu_{m(t)}$. We run the regression separately for different fund types, including government, investment grade, high yield, and bank loan mutual funds. Formally, for fund j belonging to fund category c, we have

$$\text{Outflows}_{j,t} = \beta_{1,c}\text{Treasury}_t + \beta_{2,c}\text{Corp bond}_t + \beta_{3,c}\text{Corp bond ext.}_t + \gamma_c \text{X}_t + \theta_j + \nu_{m(t)} + \epsilon_{j,t}, \quad (4.1)$$

where Treasury, Corp bond, and Corp bond ext. are dummy variables that equals one on the announcement day of Treasury purchases, corporate bond purchases (March 23), and corporate bond extension purchases (April 9), respectively.[8]

From the results in Table 8, we see that the announced expansion of the corporate bond purchases on April 9 were effective at alleviating outflows at investment-grade, high-yield, and bank loan corporate funds. This is in contrast to the purchase of Treasuries, which did not mitigate fund outflows. Quantitatively, the announcement of the corporate bond purchase expansion (April 9) reduced daily outflows at investment-grade and high-yield funds by 3.9 and 6.9 basis points. Given our event-window of one day and the persistent nature of fund flows, the policy announcement likely had a more pronounced sustained impact on curbing fund outflows as also evident from Figure 6. Our findings are consistent with Falato, Goldstein and Hortacsu (2020), who also show that the announcement of the corporate bond extension program on April 9 had the largest impact on fund outflows.

Our model provides a coherent explanation for the above findings. The Fed's commitment to buy a security corresponds to an improvement in its expected long-run return, where the effect is more pronounced for securities more exposed to the pandemic such as high-yield 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). Notice that the expectation of future returns affects investors immediate redemption decisions, which may explain the significant size of the announcement effect itself. On the other hand, expected purchases of Treasury securities cannot improve investor expectations about the future fundamentals of long-term risky assets, so that there is no clear impact on fund flows.

4.2 Announcement Effect on Fund NAVs

We proceed with exporing the announcement effects on fund NAVs. As before, we regress daily fund-level NAVs againt indicator variables corresponding to the announcement dates (equation (4.2)).We control for the trajectory of the pandemic using the growth rate of infections X_t, use fund fixed effects to remove fund-level heterogeneities θ_j, and absorb time trends using month

[8]Note that the Treasury purchase dummy equals one on March 16, 2020, because the announcement was made at 5 pm on March 15, 2020, after the markets close.

fixed effects $\nu_{m(t)}$. We present the estimation results in Table 9. The four columns correspond to the results for government, investment grade, high yield, and bank loan mutual funds.

$$\text{NAV}_{j,t} = \beta_{1,c}\text{Treasury}_t + \beta_{2,c}\text{Corp bond}_t + \beta_{3,c}\text{Corp bond ext.}_t + \gamma_c \text{X}_t + \theta_j + \nu_{m(t)} + \epsilon_{j,t}. \quad (4.2)$$

The announcement effects on fund NAVs are largely aligned with the announcement effect on fund outflows. From Table 9, we see that extending corporate bond purchases on April 9 lead to the largest and most consistent increase in fund NAVs. Quantitatively, daily NAV growth increased by 1.6% for both investment-grade and high-yield funds. For bank loan funds and government funds, NAV also increaed by 1.1% and 0.4%, respectively.

These NAV improvements could stem from a reduction in fund outflows, which reduced the need to liquidate assets at short notice and thus alleviated the impact of liquidation discounts on fund NAVs. Alternatively, there may also have been a direct announcement effect on the valuation of corporate bonds held in funds' portfolios that raised fund NAVs. One evidence in support of the former channel is provided by government funds, which experienced an increase in NAVs following the announcement of the corporate bond extension. This may seem surprising at first because government bond funds do not directly hold corporate bonds. If anything, demand may shift away from government funds towards fund types directly benefiting from the announced corporate bond purchases. However, our model suggests that if the announcement of corporate bond purchases curbs outflows at corporate bond funds, their liquidation of relatively liquid assets like Treasuries will be reduced, which will in turn lower the price pressure in the Treasury markets, improving the NAV of government funds. Therefore, the impovement in government fund NAVs points to the reduction in fund outflows as an economically important channel in explaning the announcemnt effects.

4.3 Announcement Effect on Asset Prices

Finally, we evaluate whether the announcement effect of Fed interventions on mutual fund outflows and liquidations contributed to changes in observed asset prices.

We examine how the announcement on bond returns varies with the liquidation rank of bonds in funds' portfolios. Specifically, we regress daily returns for bond i at time t against announcement dummies interacted with an indicator variable equal to one when the bond's liquidation rank, as defined by equation (3.6), is above median. As before, we control for rating-time, maturity-time and issuer-time fixed effects to prevent shocks to specific issuers, ratings and maturity buckets on days with policy announcements to drive our results. A bond fixed effect is also included to account for any remaining differences in bond-specific returns. Equation (4.3) details the most restrictive specification we run, for which results are displayed in column 4 of Table 10. Results in columns 1 to 3 are based on the same specification with different sets of fixed effects.

$$\begin{aligned} \text{Returns}_{i,t} &= \beta_1 \text{Treasury}_t * \text{High Rank}_i + \beta_2 \text{Corp bond}_t * \text{High Rank}_i \\ &\quad + \beta_3 \text{Corp bond ext.}_t * \text{High Rank}_i + \gamma \text{X}_{i,t} + \delta_i + \kappa_{f(i),t} + \tau_{m(i),t} + \omega_{r(i),t} + \epsilon_{i,t}. \end{aligned} \tag{4.3}$$

If the announcement of Fed interventions were effective at improving bond returns through reducing fund outflows and their subsequent asset liquidations, then it should be those bonds that are more likely to be sold by funds that benefit the most in terms of their returns. In this case, we expect the coefficient on the interaction term to be positive and significant since bonds with higher liquidation ranks are more likely to be sold absent the intervention (see section 3.3).

In Table 10, the coefficient on the interaction between high liquidation ranked bonds and the corporate bond extension program announcement is positive and significant in all four columns. This implies that returns on bonds higher up in the pecking order of liquidations indeed benefitted more from the April 9 announcement. The results in column 4 indicate that within bonds by the same issuer and of the same rating and maturity bucket, those with an above-median liquidation rank experienced a 10.9 basis point larger increase in returns following the announcement than bonds with a below-median liquidation rank.

Further, only the coefficient for the corporate bond extension program announcement is positive and significant, while the earlier announcements of Treasury purchases and corporate bond purchases mostly have negative coefficients on the interaction terms. This finding aligns with the announcement effect on fund outflows and the pecking order of liquidations. Table 8 shows that the March 15 and March 23 announcements could not effectively alleviate fund outflows. With continued outflows, the pecking order of liquidations implies that bonds with higher liquidation ranks are more likely to be sold and suffer lower returns, just as the negative coefficients in Table 10 suggest.

Taken together, our results in this section show 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 perform liquidity transformation. During the Covid-19 crisis, central bank support for illiquidd 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, which trickled down to alleviate strains on asset prices. In contrast, the purchase of liquid assets like Treasuries did not have a clear effect on curbing investor redemptions.[9] 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, there can be large and concentrated selling pressures in more liquid assets. This may challenge the "safe haven" status of US Treasuries in the long run (Duffie, 2020). Strains in secondary corporate bond markets, if left unresolved, may also spill over to affect primary market issuance and thus the funding supply for firms.

[9] Our model suggests that they may reduce the liquidation discount of selling Treasuries.

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.

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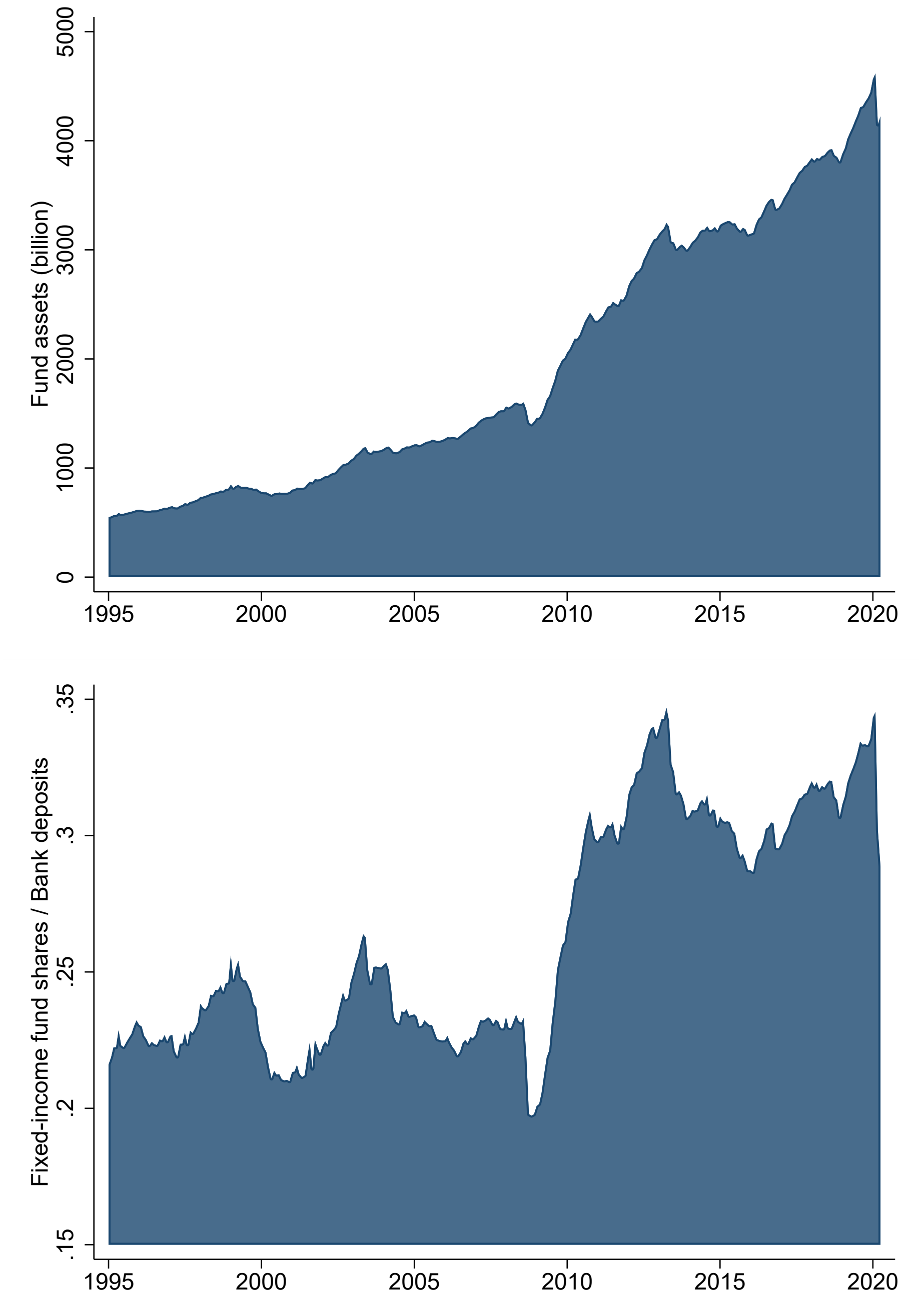

Figure 1: Size of the US Fixed-Income Mutual Fund Sector

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.

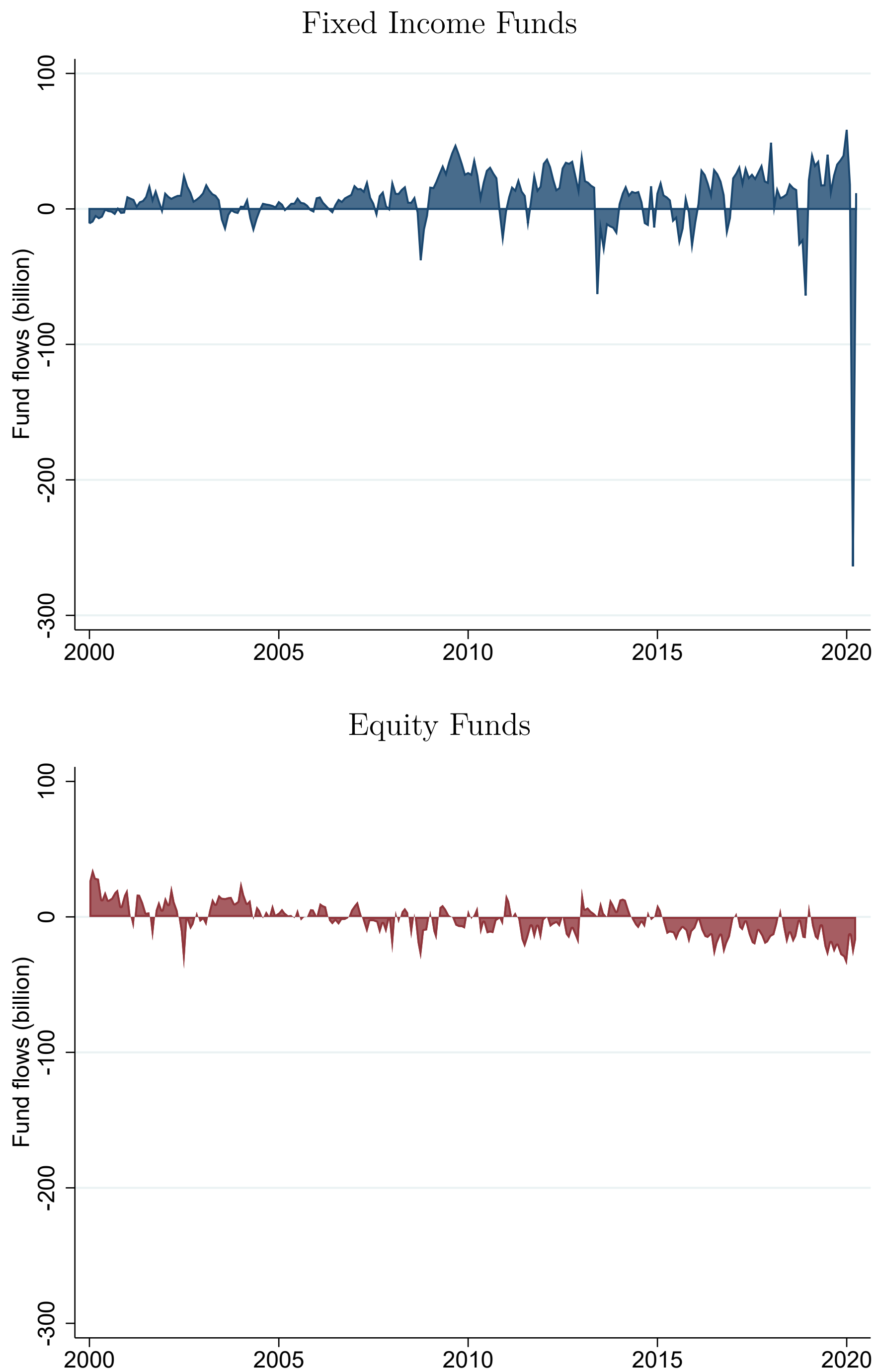

Figure 2: Fund Flows to US Fixed-Income and Equity Funds
The upper plots monthly fund flows to US fixed-income mutual funds from 2000 to 2020. The lower plots monthly fund flows to US equity mutual funds from 2000 to 2020. Data source: Morningstar.

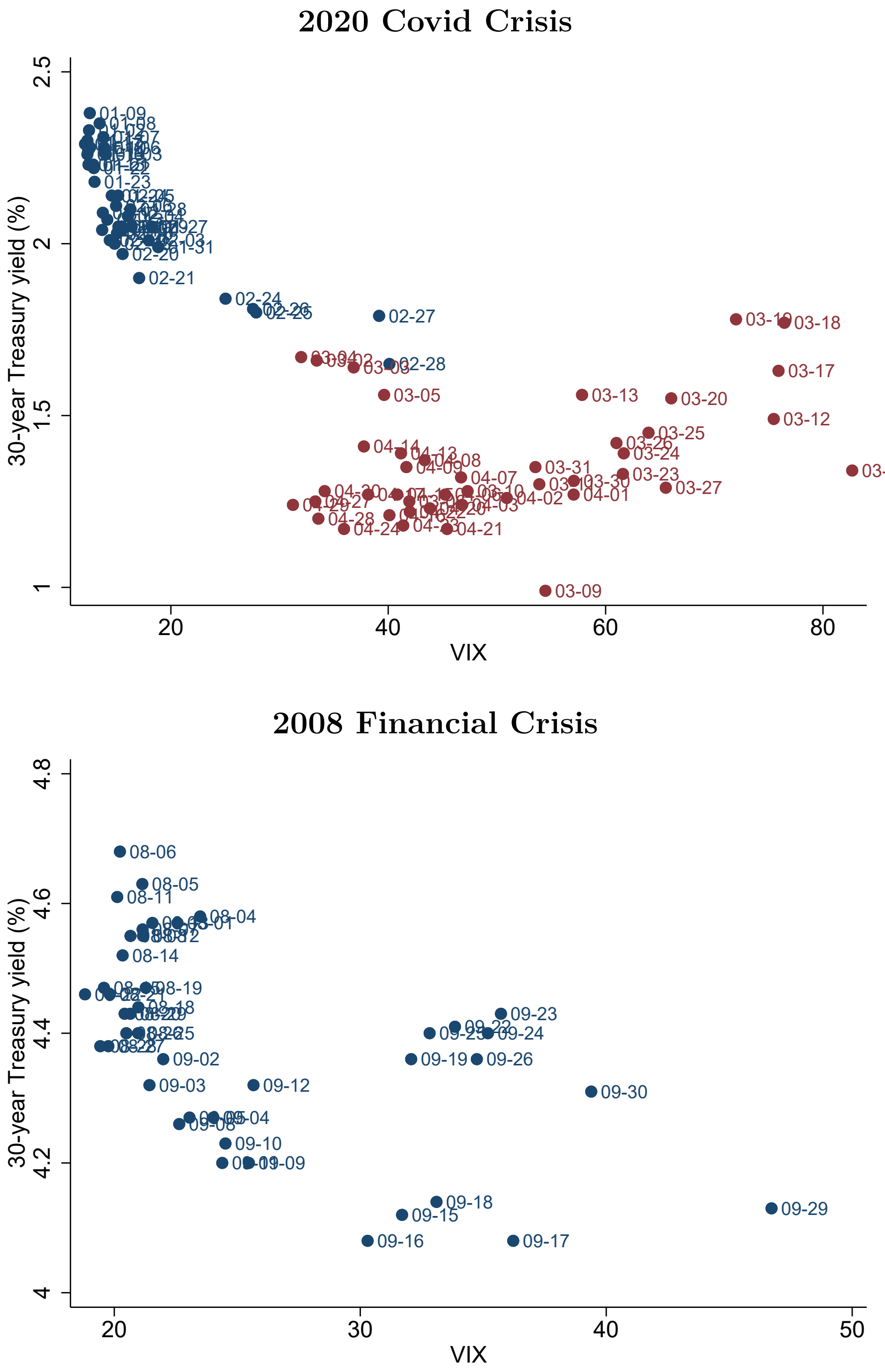

Figure 3: Relationship between Treasury Yield and VIX

This figure shows the scatter plots of 30-year US Treasury yields against the VIX. The upper panel shows the 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 2008 financial crisis from August 1, 2008 to September 30, 2008. Data source: FRED.

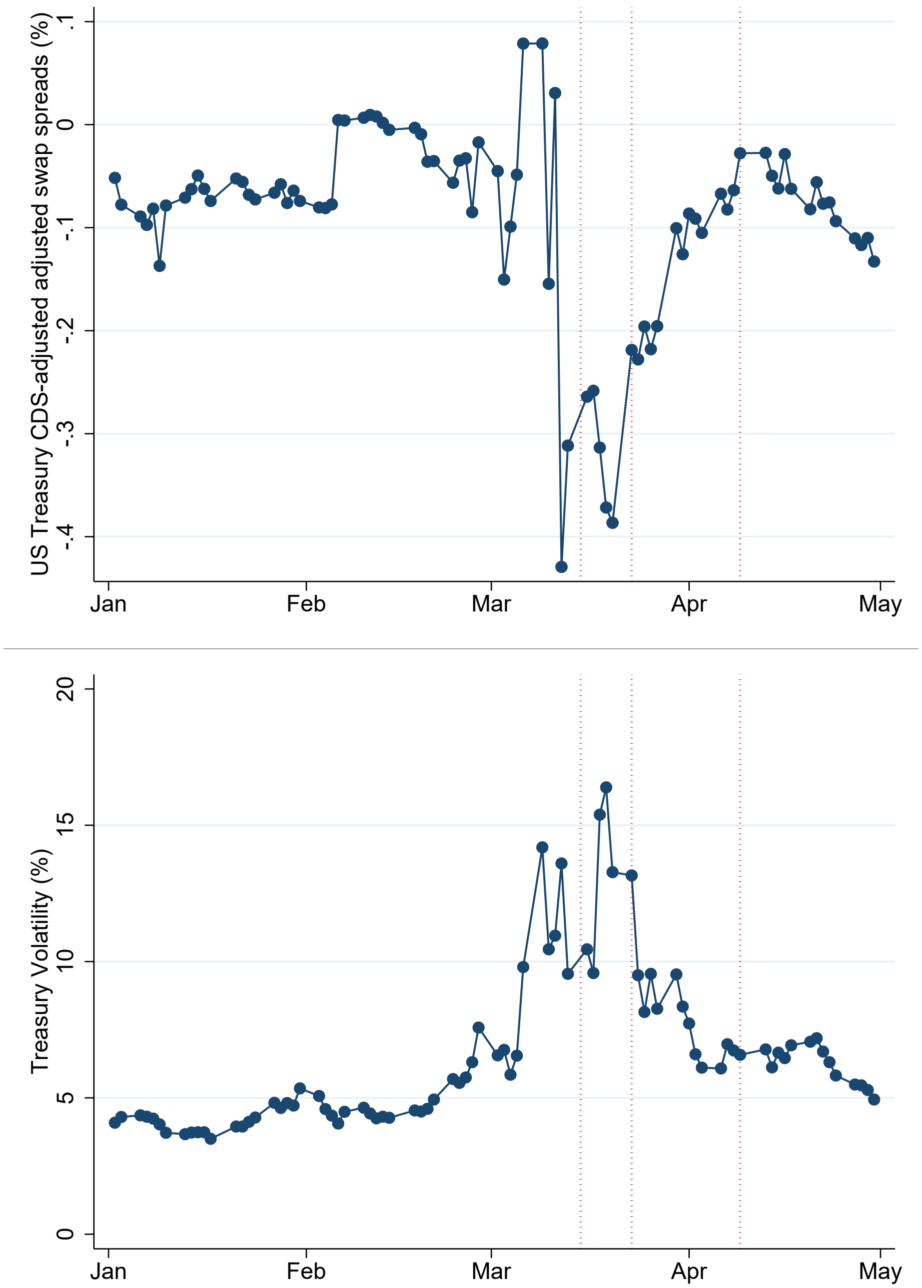

Figure 4: Treasury CDS-adjusted Swap Spreads and Volatility during Covid-19
The upper panel plots the 30-year US Treasury CDS-adjusted adjusted swap spreads, which is defined as the interest swap rate plus the sovereign CDS rate minus the Treasury yield. The lower panel plots the CBOE 10-Year Treasury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

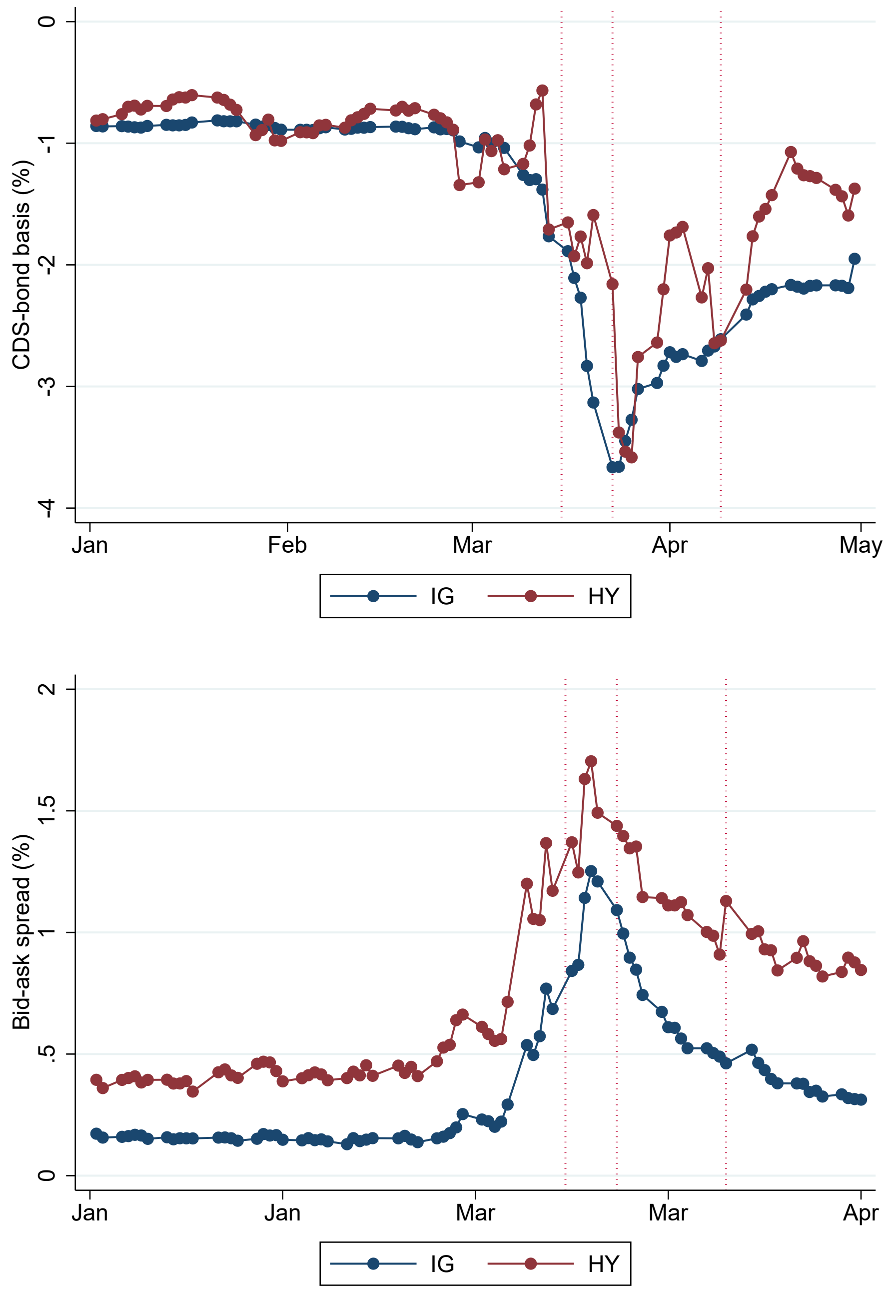

Figure 5: CDS-Bond Basis and Bid-Ask Spreads of US Corporate Bonds
The upper panel plots the US corporate bond CDS basis, defined as the difference between the corporate bond CDS and the corporate bond yield spread. The lower panel plots the bid-ask spreads. The solid and dashed line indicate investment-grade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

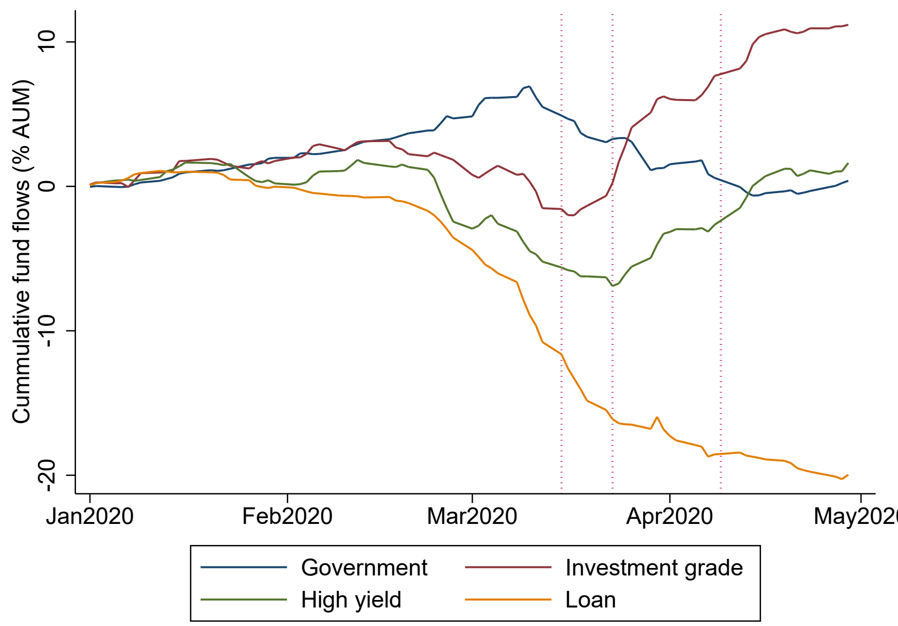

Figure 6: Cumulative Fund Flows of US Fixed-Income Funds by Fund Type
This graph plots asset-weighted cumulative fund flows for US fixed-income funds. The sample period is from January 1, 2020 to April 30, 2020. Data source: Morningstar.

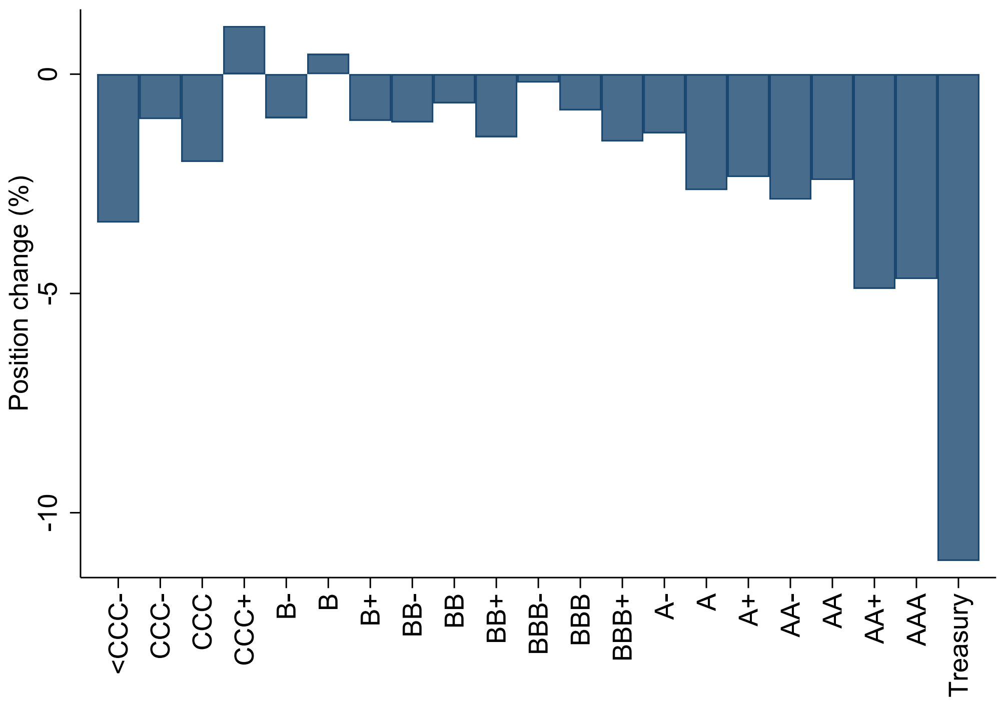

Figure 7: Liquidation by Bond Type in March 2020

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.

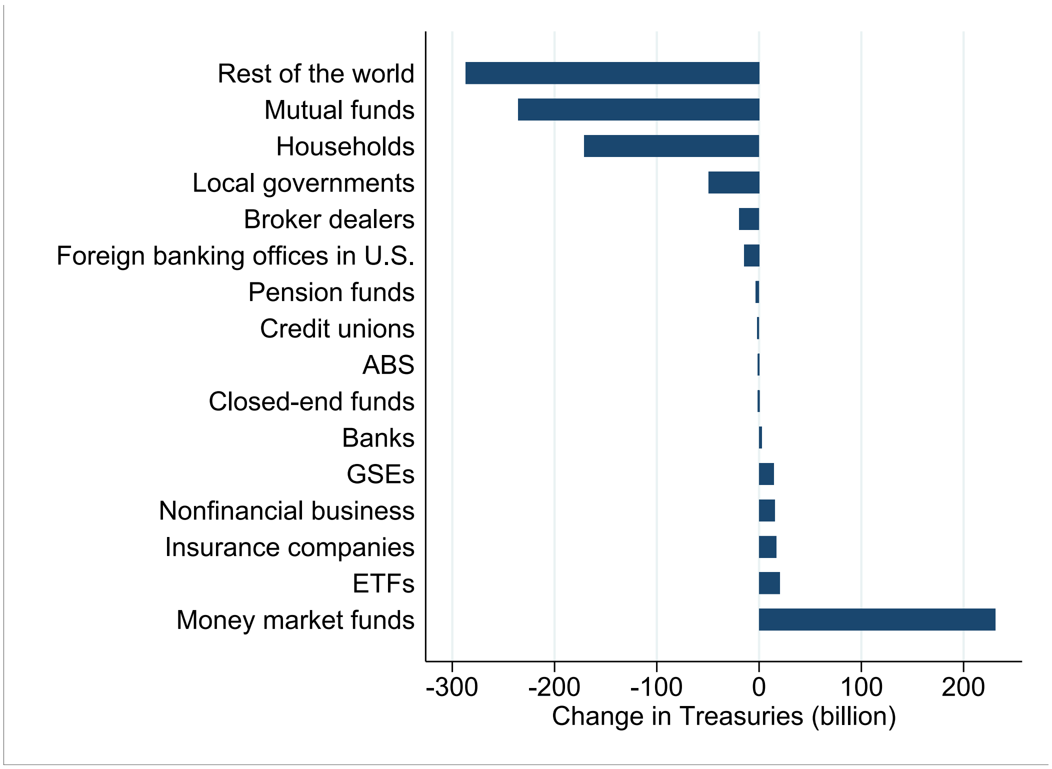

Figure 8: Changes in Treasuries Holding in 2020Q1

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

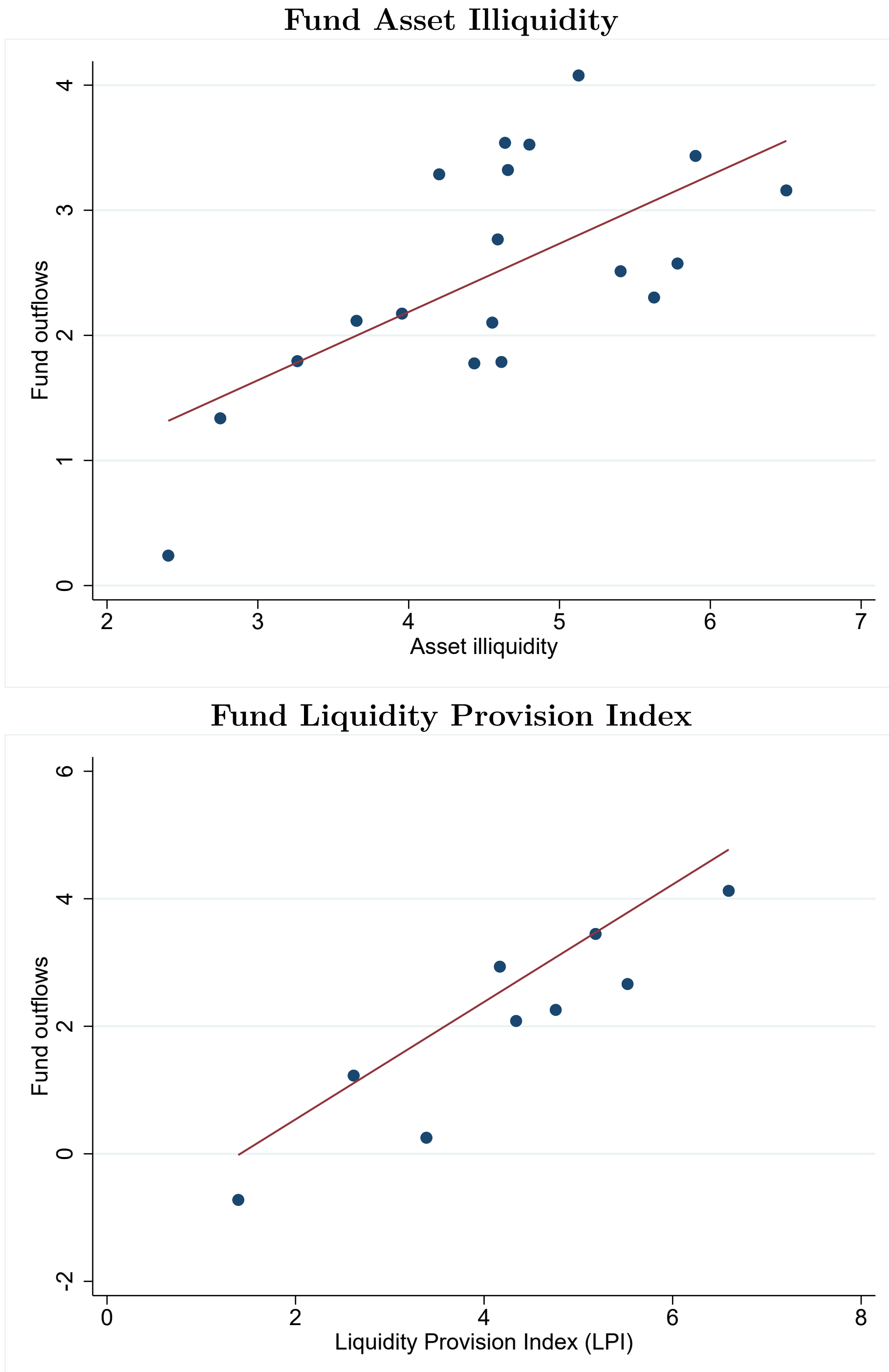

Figure 9: Fund Illiquidity, Liquidity Provision, and Cumulative Fund Outflows
The upper panel is a binned-scatter plot of cumulative fund outflows in March 2020 against funds' asset illiquidity by the end of 2019. The lower panel is a binned-scatter plot of fund outflows in March 2020 against funds'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

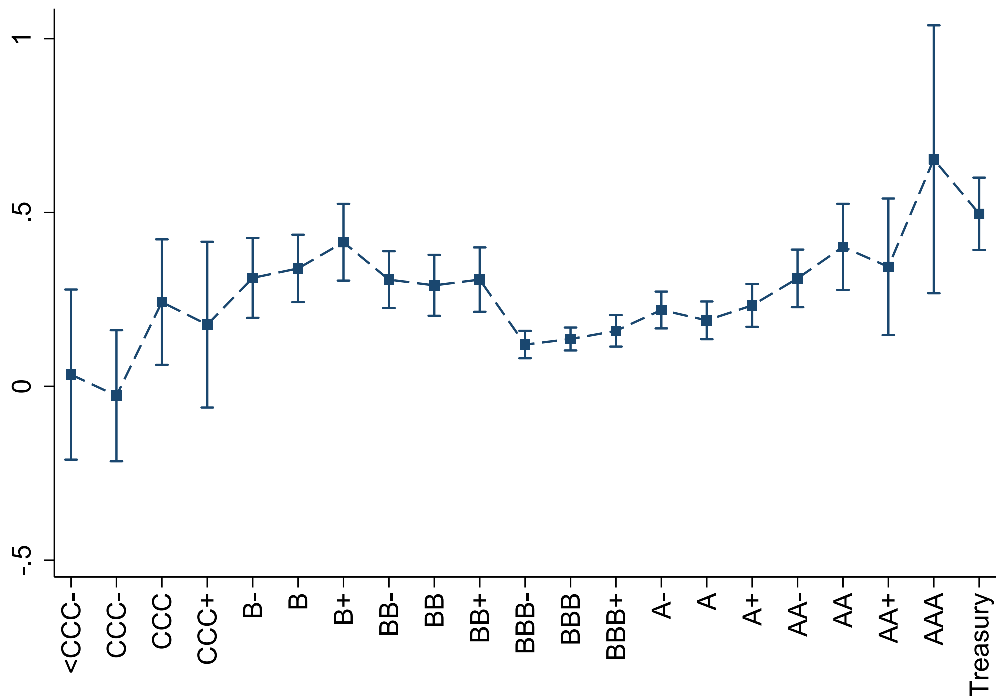

Figure 10: Liquidation-Outflow Sensitivity

This graph plots the liquidation-to-outflow sensitivities for different types of bonds. The regression model is defined in equation (3.3). The sample includes actively-managed open-end funds in March 2020. 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.

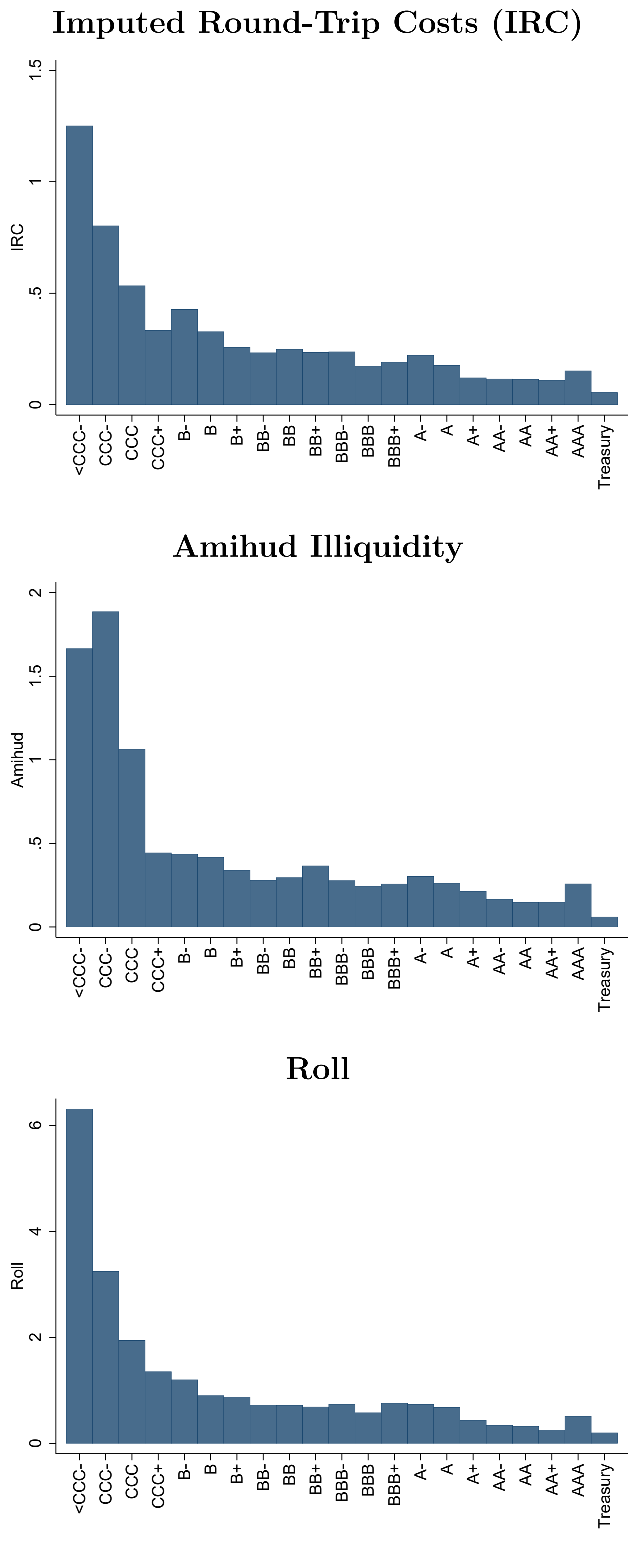

Figure 11: Liquidity Measure

This graph plots measures of illiquidity by bond liquidity group. The sample period is 2019Q4. Imputed round-trip costs (IRC) is the difference between the highest and lowest price in a set of imputed round-trip trades. Amihud Illiquidity is the price impact of a trade per unit traded. Roll measures the auto-correlation of bond returns. Data source: TRACE, Mergent.

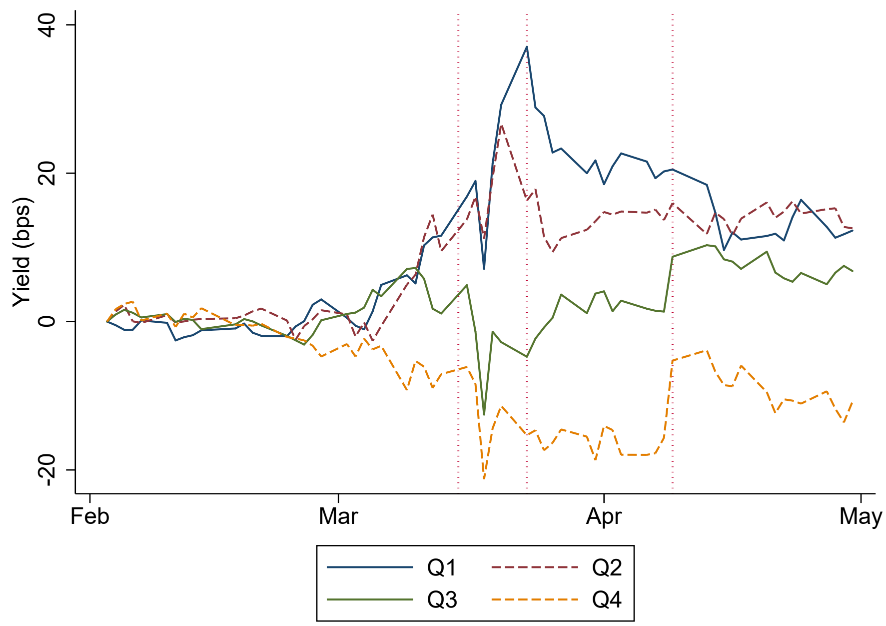

Figure 12: Bond Yields and Pecking Order

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. 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
Return	-5.801	4.881	-12.819	-9.257	-4.580	-2.535	-0.547
Asset 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
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

This table presents summary statistics of portfolio holdings of US fixed-income mutual funds in March 2020. The outflows are defined as percentage of assets under management. The returns, volatility, yield, expense ratios. are in percent. The maturity is defined as the average maturity of the bonds in the portfolio, and is quoted in years. Data source: CRSP.

Table 3: Fund Asset Illiquidity and Fund Outflows

	(1) Outflow	(2) Outflow	(3) Outflow	(4) Outflow
Asset 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]
Fund 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. "Asset illiquidity' is the weighted average of bonds' haircuts in the fund portfolio.. "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. 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]
Fund 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. The sample includes all U.S. fixed-income open-end mutual funds. Data source: CRSP.

Table 5: Pecking Order and Liquidation-Outflow Sensitivity

	(1) Open-end All	(2) Open-end Active	(3) Open-end Passive
Outflows	0.268***	0.208***	0.224***
	[0.016]	[0.024]	[0.035]
Outflows*Rank	0.198***	0.386***	0.082
	[0.047]	[0.060]	[0.151]
Bond F.E.	Yes	Yes	Yes
Fund objective F.E.	Yes	Yes	Yes
Observations	79,050	37,945	39,410
Adj. R-squared	0.067	0.071	0.050

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 are expressed as percentage. 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 2019Q4. The sample includes fixed-income securities held by fixed-income mutual funds as of 2019Q4. Data source: CRSP and TRACE.

Table 6: Effect of Fund Outflows on Bond Returns

	(1) Return	(2) Return	(3) Return	(4) Return
Imputed outflow	-2.014***	-1.903***	-2.063***	-1.743**
	[0.683]	[0.685]	[0.702]	[0.760]
Control	Yes	Yes	Yes	Yes
Rating-Time F.E.	Yes	Yes	Yes	Yes
Maturity-Time F.E.	Yes	Yes	Yes	Yes
Issuer-Time F.E.	No	No	No	Yes
Issuer F.E.	No	Yes	No	No
Bond F.E.	No	No	Yes	Yes
Observations	470,308	470,308	470,307	438,582
Adj. R-squared	0.181	0.184	0.175	0.260

This table presents a panel regression of daily security-level returns on the average outflows at funds holding the security. 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 control variable is ETF outflows. The sample includes all fixed-income securities held by fixed-income mutual funds as of 2019Q4. Data source: CRSP and TRACE.

Table 7: Effect of Pecking Order Adjusted Fund Outflows on Bond Returns

	(1)	(2)	(3)	(4)
	Return	Return	Return	Return
Liquidation-adjusted outflow	-5.153***	-4.918***	-5.221***	-3.977*
	[1.848]	[1.855]	[1.900]	[2.056]
Control	Yes	Yes	Yes	Yes
Rating-Time F.E.	Yes	Yes	Yes	Yes
Maturity-Time F.E.	Yes	Yes	Yes	Yes
Issuer-Time F.E.	No	No	No	Yes
Issuer F.E.	No	Yes	No	No
Bond F.E.	No	No	Yes	Yes
Observations	470,208	470,208	470,207	438,482
Adj. R-squared	0.181	0.184	0.175	0.260

This table presents a panel regression of daily security-level returns on the average pecking-order adjusted outflows at funds holding the security. The sample period is from Jan 1, 2020 to March 31, 2020. Bond returns are expressed in basis points. Adjusted imputed outflows are expressed in percentage points. The control variable is ETF outflows. The sample includes all fixed-income securities held by fixed-income mutual funds as of 2019Q4. 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 extension	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 on announcements of Federal Reserve interventions. 'Treasury bond purchase" refers to the announcement of buying Treasury securities and 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 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 control variable includes daily infection growth rates. The sample includes all the fixed-income mutual funds that have daily flows and NAVs in the Morningstar database. Standard errors in brackets are clustered by fund and date. Data source: Morningstar.

Table 9: Federal Reserve Announcement Effects on Fund NAVs

	(1)	(2)	(3)	(4)
	Govt	IG	HY	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 extension	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 Treasury securities and 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 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 control variable includes daily infection growth rates. The sample includes all the fixed-income mutual funds that have daily flows and NAVs in the Morningstar database. Standard errors in brackets are clustered by fund and date. Data source: Morningstar.

Table 10: Federal Reserve Announcement Effects on Bond Returns

	(1) Return	(2) Return	(3) Return	(4) Return
Treasury bond purchase*High rank	-15.427***	-14.055***	-13.698***	-9.675***
	[2.173]	[2.221]	[2.390]	[1.693]
Corp bond purchase*High rank	-12.314***	-10.950***	-10.590***	4.143
	[1.184]	[1.710]	[2.367]	[2.727]
Corp bond purchase extension*High rank	15.991***	17.353***	17.709***	10.874***
	[2.068]	[2.146]	[2.241]	[2.374]
Rating-Time F.E.	Yes	Yes	Yes	Yes
Maturity-Time F.E.	Yes	Yes	Yes	Yes
Issuer-Time F.E.	No	No	No	Yes
Issuer F.E.	No	Yes	No	No
Bond F.E.	No	No	Yes	Yes
Observations	695,757	695,757	695,756	633,286
Adj. R-squared	0.143	0.144	0.137	0.233

This table presents panel regressions of daily security-level returns on announcements of Federal Reserve interventions. 'Treasury bond purchase" refers to the announcement of buying Treasury securities and 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 the inclusion of high-yield bonds that were investment grade as of March 22. High rank is a dummy variable that equals one if the relative liquidity rank is above median. Bond returns are expressed in basis points. The sample includes Treasury securities and corporate bonds held by fixed-income mutual funds. The sample period is from January 1, 2020 to April 30, 2020. Standard errors in brackets are clustered by bond and date. Data source: CRSP and TRACE.

Appendix

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 help uncover the consequences of liquidity transformation by mutual funds and provide a unified account for the empirical analysis.

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 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. 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. 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 $t = 1$ is given by

$$NAV_1 = x - (1 - \mu)\phi_x l_x + y - (1 - \mu)\phi_y l_y \, .^{10} \tag{A.1}$$

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.[11] However,

[10] 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.

[11] 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 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.[12]

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 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.*

[12] 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.

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.[13]

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 $t = 1$:[14]

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 $t = 0$ 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:*

[13]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.

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

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

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.*

Proposition 2 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

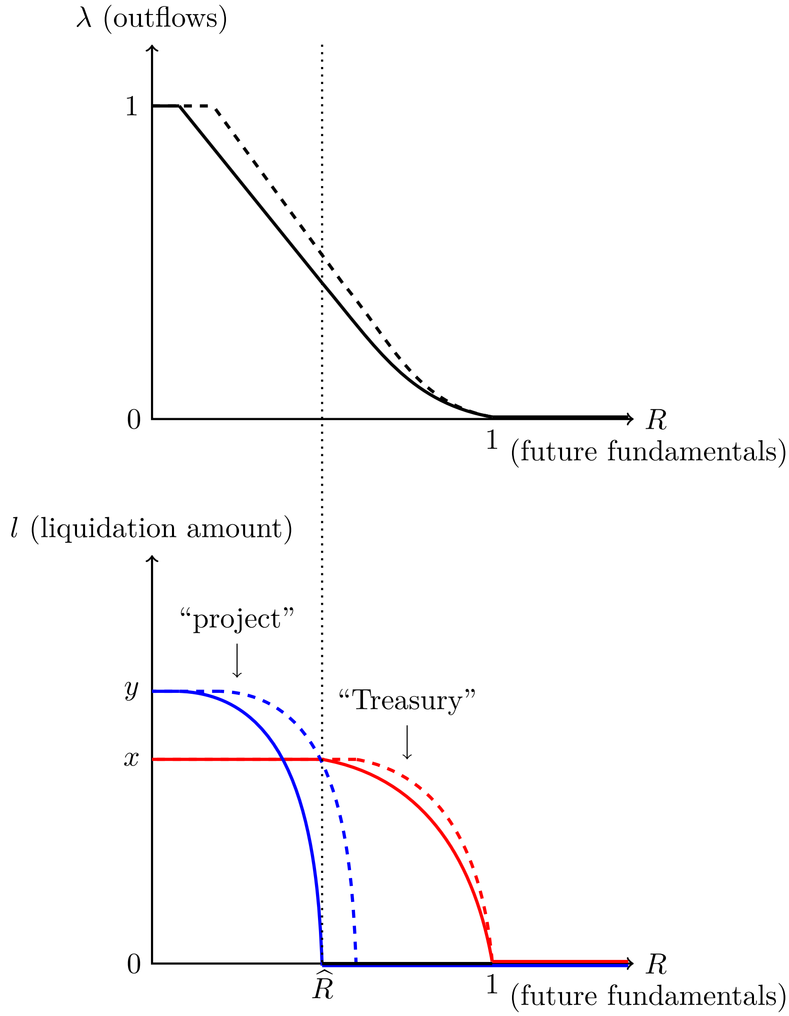

Figure A1: Fund NAV Stickiness, Fund Flows, and Reserve Flight to Liquidity

to larger outflows have to liquidate more Treasuries when reverse flight to liquidity occurs. Figure A1 provides an illustration of Propositions 1 and 2, which shows that the more liquidity transformation is conducted by mutual funds, the more outflows occur, and ultimately more Treasury is liquidated.

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 $G(R)$, then 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.*

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.

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 $\phi_x' < \phi_x$, then 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.*

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.

B 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

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

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:

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

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

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

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

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

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

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

where $\widehat{R}$ is given by (B.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 (B.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 (B.1) and (B.2), we can express l_x as a function of λ:

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

which implies that

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

and by NAV equation (B.3)

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

both being functions of λ.

Plugging equations (B.7) and (B.8) into the equilibrium condition (B.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

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

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 $(0,1)$:

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

which is strictly decreasing in R. Note that (B.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 (B.1) and (B.2) yields

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

which combined with (B.3) further yields

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

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

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

which is also decreasing in R and subject to $\lambda^*(R) \leq 1$. Similarly, note that (B.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

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

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

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

which then by (B.6) immediately yields (B.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 (B.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 (B.5).

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 (B.1), (B.2), (B.3), and (B.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 (B.1) and (B.2), we have

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

and by NAV equation (B.3)

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

both being functions of λ.

Plugging equations (B.15) and (B.16) into the equilibrium condition (B.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:

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

in which $NAV_1(\lambda)$ and $NAV_2(\lambda)$ are given by (B.1) and (B.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 (B.10) and (B.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

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

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. ∎