Bond Mutual Funds: Systemic Liquidity and Derivative Use *

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Abstract

We show, both theoretically and empirically, that there is a systemic component to liquidity management by bond mutual funds. A fund's cash holding relative to its investor flows affects its optimal trading. At an aggregate level, aggregate cash relative to aggregate investor flows affects aggregate trading, which in turn affects bond prices, returns, and liquidity. Funds factor in other funds' cash holdings and investor flows when trading optimally, since an aggregate cash shortfall may induce downward price pressure on bonds which many funds are liquidating at the same time. This is especially important during crisis periods for bond mutual funds who exhibit a pecking order from liquidating cash to less liquid corporate bonds when financing fund outflows. We also use novel data on derivative holdings to document large cross-sectional variation in how bond mutual funds use them, and its implications on liquidity management: some hedging their returns, some amplifying them, some not using them at all.

Keywords: Systemic liquidity management, Derivatives, Cash holdings, Pecking order, Hedging

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1 Introduction

We show, both theoretically and empirically, that bond mutual funds' optimal trading depends not only on their own portfolio holdings of cash, bonds, derivatives, and other assets, and their own investor fund flows, but also the trading of other funds, which in turn is driven by those other funds' portfolio holdings and their fund flows. This represents a systemic component to bond mutual fund trading, and impacts bond prices, returns, and liquidity costs.

Open-end bond mutual funds are large and important institutions who hold large proportions of their portfolios in corporate bonds. They need to trade them regularly, both to actively try to achieve higher long-term returns than their competitors and to regularly service investor flows in and out of the fund by trading in the secondary market. The timing of these flows is typically positively correlated across the cross-section of funds, as investors' demand to invest and redeem has a systematic component which is correlated with the direction of the market and broader macroeconomy, with investors more likely to withdraw when fund performance is low, particularly during market downturns which negatively affect most funds. As a result, mutual funds often want to trade the same securities, and in the same direction, as other funds, particularly when fund returns are low (Goldstein et al. (2017), Cai et al. (2019), and Falato et al. (2021)). So the illiquidity spillover from aggregate trading represents a negative externality imposed on funds' secondary market trading, and this contributes to systemic liquidity risk in the corporate bond market, with liquidity costs exacerbated at the most inopportune times and in the most inopportune bonds, as prices are driven lower by price pressure, in an over-the-counter (OTC) dealer market where there typically isn't much depth without a price concession.

Even in times where prices aren't falling, liquidity for most bonds is relatively weak compared to equities (Bao et al. (2011), Dick-Nielsen et al. (2012), and Randall (2021a)), so to mitigate the high cost of trading regularly and in large size, funds use their cash reserves (Chernenko and Sunderam (2020a) and Pastor et al. (2020)), and, more recently derivatives, to manage the liquidity risk of investor redemptions from their portfolios. As a result, funds face trading costs which depend not just on their own trading, but also other funds' trading too.

We first model the theoretical trade-offs that funds face when they use cash to invest in risky assets, like corporate bonds. The benefit is a higher expected return from the risky asset over safe cash. But the costs are several: an increase in the market risk of their portfolio, whose cost is magnified by funds' risk aversion or value-at-risk constraints; an increase in the chance of a cash shortfall if their future fund outflows exceed their inflows and cash reserves; and, in the event of a cash shortfall, an increase in liquidity costs from liquidating bonds, which they sell at a larger haircut than cash. The magnitude of the haircut they face if they need to sell bonds is modeled as proportional to the total quantity of selling of that bond by all funds, representing temporary price pressure, so liquidity costs are particularly large when funds' trading is positively correlated and large, for instance due to correlated fund flows, if a fund is trading in the same direction as the herd. The functional form for the price and haircut can be motivated for instance by Randall (2021b) who shows theoretically that the deviation of an asset price from fundamental value in an OTC dealer market is proportional to the endogenously negotiated trade size, where the coefficient of proportionality is a function of dealer:customer relative bargaining power, bond risk, dealers' inventory costs or effective risk aversion, and the expected time to find another counterparty.

Solving our model, and using market clearing, gives expressions for funds' optimal trading, expected bond return, expected liquidity haircut, and the liquidity-value-at-risk combining the probability of a cash shortfall with the liquidity cost of selling illiquid bonds due to that shortfall. The liquidity haircut is endogenously determined through the aggregate equilibrium trading of all funds which sets the asset's price. The model highlights how funds' cash holding, optimal trading, and assets' expected returns and liquidity costs, are determined not just by funds' individual portfolio holdings and fund flows, but also by the aggregate portfolio holdings and fund flows of other funds. This emphasizes and motivates the systemic component to liquidity risk, which we test and verify using bond mutual fund data.

Empirically, we find that bond mutual funds' corporate and government bond trading is positively correlated with investor fund flows, both for inflows and outflows. When funds have higher outflows, particularly as a proportion of their cash reserves, there is a pecking order of what they choose to sell: they liquidate more corporate bonds, but less so if they hold a higher percentage of cash. With larger redemptions, funds tend to liquidate more bonds with worse credit ratings, simultaneously releasing cash and reducing the market risk of their portfolio. Liquidity costs and the change in liquidity costs increase when other mutual funds are selling the same security in larger size. At the start of the Covid-19 pandemic, bonds traded by funds with larger cash shortfalls had higher liquidity costs and lower bond returns. The evidence for a pecking order when liquidating assets to meet investor redemptions magnifies the systemic importance of other funds' holdings, as it concentrates selling in certain assets.

Bond mutual funds hold more than just cash and bonds. In particular they also hold derivatives and file their positions with the SEC. We collected this derivative holding data in the months pre-Covid, at the start of the Covid outbreak, and in the recovery phase, seeing interesting dynamics over that tumultuous time. About half the funds in our sample hold at least one derivative at least one point in time. Of those, some use them to hedge their returns and some to amplify them. On average hedging funds hold less cash, more corporate bonds, and larger derivative positions than amplifying funds. Overall, though, hedging funds have lower systematic bond market risk than amplifying funds. Net fund inflows tend to be higher for amplifying funds, but also more volatile, than for hedging funds. Amplifying funds' trading is sensitive to the interaction of fund flows with cash, while hedging funds' trading is sensitive to the interaction of fund flows with liquidity costs, as amplifying funds typically hold enough cash to satisfy investor outflows, whereas hedging funds hold less cash, and so are more likely to have to liquidate bonds to satisfy outflows. Amplifying funds typically attract investor inflows while hedging funds have outflows. The theoretical model suggests a key driver of funds' trading is the probability of a future cash shortfall from fund outflows exceeding cash reserves. We use the distribution of fund flows to estimate this probability in the pre-Covid and recovery phases, seeing substantial variation both cross-sectionally between funds, and in the time-series before, during, and after the outbreak of Covid-19. Some of this variation could be explained by the variation in the risk and liquidity of their portfolios.

Amplifying funds, with higher market beta, consistently produced higher returns than hedging funds until the recovery period, though overall hedging funds had a significantly positive alpha, while those for amplifying funds and funds without derivatives were not statistically different from zero. Expense ratios are higher for hedging funds than amplifying funds on average, but their total net assets are lower.

Relation to existing literature

There is a growing literature on bond mutual funds' flows, trading, and cash management, and the key role they play in corporate bond liquidity, given their significant size in the market, and the regular trades they need to make due to fund flows, particularly investor redemptions.

Goldstein et al. (2017) find that bond fund outflows are more sensitive to bad performance than their inflows are sensitive to good performance, particularly when they have more illiquid assets and when market illiquidity is high. Cai et al. (2019) find evidence of institutional herding in the corporate bond market, particularly when selling, for speculative-grade, small, and illiquid bonds, and during the financial crisis. Connor and Leland (1995)'s theoretical model shows that funds maintain a cash position in a min-max range, only actively changing it when in-/out-flows are extreme, trading off expected return and tracking error with transaction costs. Pastor et al. (2020) find that funds with larger size, lower expense ratios, and higher turnover hold more liquid portfolios. Chernenko and Sunderam (2020a) find that mutual funds hold cash to accommodate flows, but don't fully mitigate price impact. Falato et al. (2021) find that fire-sales which are induced by redemptions have spillover effects among funds with the same assets. Morris et al. (2017) show theoretically, if asset managers use cash holdings as a buffer to meet redemptions, they can mitigate fire sales of their assets. If they hoard cash in response to redemptions, they will amplify fire sales. Empirically, cash hoarding is found to be the rule rather than the exception, and less liquid bond funds display stronger cash hoarding. Choi et al. (2020) find little evidence that bond fund redemptions drive fire sale price pressure. They attribute their findings, which contrast with those found for equity funds, to funds' liquidity management strategies. Chernenko and Sunderam (2020b) construct a measure of forward-looking bond market liquidity which captures funds' expectations of future liquidity, using the strength of the cross-sectional relationship between mutual fund cash holdings and flow volatility. The motivation is that funds with more flow volatility and illiquid bonds need more cash. Jiang et al. (2021) show that during tranquil market conditions, corporate bond mutual funds reduce liquid asset holdings to meet redemptions, temporarily increasing relative exposures to illiquid asset classes. When aggregate uncertainty rises, they scale down their liquid and illiquid assets proportionally to preserve portfolio liquidity. Fund redemptions lead to more corporate bond selling during high-uncertainty periods, which generates price pressures and predicts strong return reversals. Ma et al. (2020) find that in meeting redemptions during the Covid-19 crisis, bond mutual funds first sold their more liquid assets, generating the most selling pressure in more liquid asset markets. Investors' flight to liquidity was thereby turned into an aggregate reverse flight to liquidity. The Federal Reserve's program of buying illiquid bonds alleviated fund outflows. Schrimpf et al. (2020) find that mutual funds holding illiquid assets in March 2020 added to their cash buffers even after meeting investor redemptions. Zeng (2020) models the dynamics of mutual fund runs, motivated by a first-mover advantage in redemptions. Li and Yu (2021) shows that as the risk-free rate declined recently, more short-term investors reached for yield in illiquid bonds, reducing their bid-ask spreads, but increasing the sensitivity of yields to bid-ask spreads. Simutin (2020) finds that actively managed equity funds with high excess cash outperform their low excess cash peers, by making superior stock selection decisions, and satisfying fund outflows and controlling transaction costs.

Bao et al. (2011), Dick-Nielsen et al. (2012), and Randall (2021a) show what drives corporate bond liquidity costs: search, trade frequency, dealer inventory costs, and customer:dealer bargaining power.

There is relatively little literature on derivative use by mutual funds. Two recent working papers are Kaniel and Wang (2021), who examine derivative use for equity mutual funds, and Sialm and Zhu (2021), who examine currency derivative use in fixed income mutual funds.

Section 2 describes the model and predictions. Section 3 describes the data. Section 4 describes the empirical analysis. Section 5 concludes. Proofs related to the model are in the Appendix.

2 Model

We solve a model of mutual fund trading to help develop our intuition around the trade-offs faced by mutual funds when trading bonds, and to show how bonds' endogenous liquidity costs and expected returns have systematic components driven by other funds trading, which in turn is driven by their holdings.

2.1 Set-up

There are a large number of funds, who each hold a portfolio of cash and a single bond. Their cash holding in dollars, and the number of units of the bond, leaving time t are denoted $cash_t$ and $bonds_t$, respectively. The cash is safe and completely liquid but earns zero interest, while the bond's price p_t is risky and possibly illiquid but has a positive expected return. We can think of both the return and the liquidity of the cash and the bond not just in an absolute sense, but also a relative sense, still with cash having a lower interest rate than the expected return of the risky bond, and being more liquid if not perfectly liquid. So cash here could be interpreted as a Treasury bond, for example.

There are 2 rounds of bond trading. At the start of each round funds receive random investor fund net outflows f_t or net inflows $-f_t$. The inflows arrive in the form of cash, and the outflows have to be funded by cash. The fund buys q_t units of the bond at time t, or sell $-q_t$ units. So $cash_t$ and $bonds_t$ evolve as described in the timeline.

In the final round of trading, if funds have insufficient cash to meet any net fund outflows then

Figure 1: **Timeline.** This figure shows the timeline of how a fund's cash and bond holding evolve over 2 rounds of trading

$cash_{t-1}$	$cash_{t-1} - f_t - p_t q_t = cash_t$	$cash_t - f_{t+1} - p_{t+1} q_{t+1} = cash_{t+1}$
$t-1$	t	$t+1$
$bonds_{t-1}$	$bonds_{t-1} + q_t = bonds_t$	$bonds_t + q_{t+1} = bonds_{t+1}$
$t-1$	t	$t+1$

they sell just enough bonds to meet them, otherwise they do not trade. Implicitly we are assuming a pecking order here, with funds selling their most liquid assets first (cash) before selling their next most liquid assets (bonds). Since individual funds are either selling or not trading in the final period, the total net trading of all funds is negative, and the selling pressure drives the transaction price at which the funds sell to their dealers below the bond's fundamental value. So bonds who are selling funds suffer a haircut, represented by the difference between the fundamental value and the price at which they sell.

In the first round of trading, funds face a number of trade-offs when deciding how many bonds to buy or sell. Buying more bonds will increase the expected return of their portfolio, but also increase their portfolio risk, and increase both the chance that they will have a cash shortfall to meet their net redemptions and the total slippage they would incur by having to sell more bonds if they had a shortfall at a price below the bond's fundamental value.

2.2 Bond transaction price

The price for all funds at time t is specified as

$$p_t = v_t + c_t Q_t \tag{1}$$

where v_t is the fundamental value of the bond, $c_t > 0$ is a bond-specific liquidity cost, and multiplied by Q_t, the net number of units of the bond which are bought by funds at time t. So if funds are overall net buyers, the price is above fundamental value, and if funds are overall net sellers, the price is below fundamental value. Each fund is assumed to be so small that their individual trading q_t does not affect total trading Q_t. If a fund is trading in the same direction as the market, i.e. $sign(q_t) = sign(Q_t)$, they will effectively pay a transaction cost c_tQ_t per unit traded, whether buying or selling. If they are trading in the opposite direction to the market they receive that transaction cost per unit traded. The specification of this price can be motivated by e.g. Kyle (1985) or Randall (2021b), who shows that the price for an individual customer trading with a dealer in an OTC market is $p_t = v_t + c_tq_t$ where both price and quantity are both endogenous, negotiated by Nash bargaining between customer and dealer. c_t is shown to be a function of their relatively bargaining power, the bond's trade frequency, its price risk, and the dealer's time-varying cost of holding inventory. In this paper we are effectively assuming that there is one price determined by aggregate trading of all funds. c_t could still be determined by the bond's trade frequency, and the dealer's time-varying cost of holding inventory, but not by individual customer bargaining power, but loosely some aggregate bargaining power of the funds who are trading at that point in time. The liquidity cost, i.e. the deviation of the price from fundamental value, c_tQ_t, is endogenously determined by aggregating individual trading into Q_t.

2.3 Timeline

Each fund follows the following time-line:

- Enter time t with AUM $= cash_{t-1} + bonds_{t-1}v_t$, where $bonds_{t-1}$ is the number of units of bonds held, and v_t is the fundamental value per unit.
- Get dollar outflow f_t (or inflow $-f_t$).
- Next period, at time $t+1$, if your redemptions exceed your cash, you have to liquidate enough illiquid bonds to meet that need, which may be costly if everyone else is selling too.
- So the trade-off at time t is between buying more bonds which have a higher expected return

than cash, but that increases your market risk as well as the chance of having insufficient cash and paying higher bond liquidation costs next period.

- At time t choose how many extra bonds to buy to maximise $E[cash_{t+1} + bonds_{t+1}v_{t+1}] - \lambda_t(p_t bonds_t)^2$, your risk-adjusted expected AUM next period after any liquidations.

2.4 Funds' utility

Funds maximise their utility, specified as:

$$U_t \equiv E_t \left[\underbrace{cash_{t+1} + bonds_{t+1}v_{t+1}}_{AUM_t} \right] - \underbrace{\lambda_t(p_t bonds_t)^2}_{\text{penalty for risk}} \tag{2}$$

If their risk-aversion coefficient $\lambda_t = 0$, or they don't hold any risky bonds, they are trying to maximise their assets under management (AUM), which is the sum of their cash and bond holdings, where their bond holdings are evaluated at their fundamental value rather than their price, to filter out any temporary deviations in the price from fundamental value due to price pressure if aggregate trading Q_t is not zero. They could be trying to maximise their AUM because they are paid a fixed percentage of it as a management fee at the end of the period. But they are risk-averse, so if their risk-aversion coefficient $\lambda_t 0$ is strictly positive, there is a risk penalty function proportional to the value of their risky bond holdings over the next period. This is in the same spirit as the more-conventional mean-variance set-up with risk penalty function $\lambda_t Var_t[AUM_{t+1}]$ or a value-at-risk constraint. But our current set-up is a reduced-form way of introducing risk-aversion, while still allowing closed-form solutions.

2.5 Trading

There are 2 rounds of trading. We work backwards from the final trade time.

2.5.1 Final period, time $t+1$

The fund enters time $t+1$ with $cash_t$, the same amount of cash as it had last period, since interest rates are assumed to be zero. It then receives fund outflows f_{t+1} or inflows f_{t+1}. If the fund has positive total net inflows, or sufficient cash to meet its total net outflows, it doesn't trade any bonds, and just uses its cash to pay out its net outflows, i.e. if $cash_t \geq f_{t+1}$ then $q_{t+1} = 0$. Cash is assumed to be perfectly liquid, so there is no transaction cost for this, and its cash position becomes $cash_{t+1} = cash_t - f_{t+1}$.

If the fund instead has a cash shortfall, because its cash is insufficient to cover its total net outflows, i.e. $cash_t < f_{t+1}$, then the fund drains its cash reserves, i.e. $cash_{t+1} = 0$, and sells just enough bonds to exactly cover that shortfall. We denote the amount they sell in this case as $-q^-_{t+1}$, given by:

$$-q^-_{t+1} = \frac{f_{t+1} - cash_t}{p_{t+1}} \tag{3}$$

So at time $t+1$, after trading, the fund ends up with this many units of the bond:

$$\begin{aligned} bonds_{t+1} &= bonds_{t-1} + q_t + q_{t+1} &(4)\\ &= bonds_{t-1} + q_t - \left(\frac{f_{t+1} - cash_t}{p_{t+1}}\right) 1_{cash_t < f_{t+1}} &(5) \end{aligned}$$

and this much cash:

$$\begin{aligned} cash_{t+1} &= (cash_t - f_{t+1})\, 1_{cash_t \geq f_{t+1}} &(6)\\ &= (cash_{t-1} - f_t - p_t q_t - f_{t+1})\, 1_{cash_t \geq f_{t+1}} &(7) \end{aligned}$$

2.5.2 First period: time t

In the appendix we show how we can re-write the fund's utility function by conditioning on its investor flows at time $t+1$:

$$
\begin{aligned}
& E_t\left[cash_{t+1} + bonds_{t+1} v_{t+1}\right] - \lambda_t (p_t bonds_t)^2 && (8)\\
= \; & E_t\left[E_t\left[cash_{t+1} + bonds_{t+1} v_{t+1} | f_{t+1}\right]\right] - \lambda_t (p_t bonds_t)^2 && (9)\\
= \; & \underbrace{cash_t - E_t[f_{t+1}] + (bonds_{t-1} + q_t)\, E_t[v_{t+1}]}_{\text{expected AUM if no cash shortfall}} - \underbrace{\lambda_t (p_t (bonds_{t-1} + q_t))^2}_{\text{penalty for risk}} \\
& - \underbrace{E_t\left[(p_{t+1} - v_{t+1})\, q_{t+1}^{-} \mid cash_t < f_{t+1}\right]}_{\text{expected total haircut if shortfall}} && (10)
\end{aligned}
$$

We see the trade-offs that the fund faces at the first round of trading at time t, where buying more (or selling less) of the bond, i.e. a higher q_t:

1. increases expected bond AUM, both through more units and since those units of the bond have a higher expected return than the cash which was used to buy them;
2. increases the penalty for risk over the next period (assuming long bonds entering time t);
3. decreases cash AUM;
4. increases the probability of cash shortfall next period;
5. increases the magnitude of the expected liquidity cost if there is a cash shortfall (since funds are by assumption only selling or not trading at the final time $t+1$, i.e. $Q_{t+1} < 0$, the price at which the fund sells, $p_{t+1} = v_{t+1} + c_{t+1} Q_{t+1}$, will be less than fundamental value).

To get a closed-form solution for q_t, we target an objective function which is a negative quadratic in q_t, and thus has a unique maximum. So we assume the investor flows are uniformly distributed, and independent of everything else:

$$f_{t+1} \sim Uniform\left[\underline{f}, \bar{f}\right] \tag{11}$$

The range of fund flow values need not be symmetrical around 0.

To compute the first order condition and solve for q_t, we need the sensitivities to q_t:

$$cash_t = cash_{t-1} - f_t - p_t q_t \quad \Rightarrow \quad \frac{\partial cash_t}{\partial q_t} = -p_t < 0 \tag{12}$$

$$P[cash_t < f_{t+1}] = \frac{\bar{f} - cash_t}{\bar{f} - \underline{f}} \quad \Rightarrow \quad \frac{\partial P[cash_t < f_{t+1}]}{\partial q_t} = \frac{p_t}{\bar{f} - \underline{f}} > 0 \tag{13}$$

$$q_{t+1}^{-} = \frac{cash_t - f_{t+1}}{p_{t+1}} \quad \Rightarrow \quad \frac{\partial q_{t+1}^{-}}{\partial q_t} = -\frac{p_t}{p_{t+1}} < 0 \tag{14}$$

The first order condition with respect to q_t is given by:

$$\begin{aligned} 0 \quad &= \quad E_t[v_{t+1}] - p_t - 2\lambda_t p_t^2 (bonds_{t-1} + q_t) \\ &\quad - \frac{p_t}{\bar{f} - \underline{f}} \left(cash_{t-1} - f_t - p_t q_t - \bar{f}\right) E_t \left[\frac{c_{t+1} Q_{t+1}}{p_{t+1}}\right] \end{aligned} \tag{15}$$

If c_{t+1} or $Q_{t+1} = 0$, then $p_{t+1} = v_{t+1}$, and there's no transaction cost for liquidating bonds at time $t+1$, and the fund optimally holds the following number of units of the bond after trading at time t:

$$bonds_t = q_t + bonds_{t-1} \quad = \quad \frac{E_t[v_{t+1}] - p_t}{2\lambda_t p_t^2} \tag{16}$$

More generally, substituting in the specification of the price, and simplifying, the dollar amount spent on bonds becomes:

$$p_t q_t \quad = \quad \frac{\overbrace{E_t[v_{t+1}/p_t] - 1}^{\text{expected return}} - \overbrace{2\lambda_t p_t bonds_{t-1}}^{\text{extra risk}} - \overbrace{\frac{1}{\bar{f} - \underline{f}} \left(cash_{t-1} - f_t - \bar{f}\right)}^{\text{expected shortfall at time } t+1} \overbrace{E_t \left[\frac{c_{t+1} Q_{t+1}}{p_{t+1}}\right]}^{\text{\% illiquidity}}}{2\lambda_t p_t - \frac{1}{\bar{f} - \underline{f}} E_t \left[\frac{c_{t+1} Q_{t+1}}{p_{t+1}}\right]} \tag{17}$$

Note that some of this trading is induced by investors' fund flows at time t: if there are net inflows then bonds need to be bought, and if there are net outflows then bonds need to be sold, all else equal.

Intuitively, from the fund's trade-offs when trading highlighted earlier, this amount is:

- increasing in the bond's expected return (as this makes the bond more attractive, increasing expected AUM);
- increasing in the fund's cash holding (as this both reduces the chance of a cash shortfall next period, and reduces the expected total bond liquidation cost if there is a cash shortfall, since fewer bonds would need to be sold);
- decreasing in the fund's risk-aversion (as this makes buying more risky bonds relatively less attractive compared to leaving it as risk-free cash);
- decreasing in the bond's current price (i.e. there is a downward-sloping demand curve, and writing the price as $v_t + c_t Q_t$ we see that bond buying is equivalently decreasing in other funds' current net buying, especially when the current liquidity cost is high);
- decreasing in the bond's price risk (as this makes risky bonds less attractive to risk-averse funds, who pay a penalty proportional to the square of the number of units of the bond holding);
- decreasing in the fund's expected future outflow (as higher future flows both increases the chance of a cash shortfall next period, and increases the expected total bond liquidation transaction cost if there is a cash shortfall, since more bonds would need to be sold);
- decreasing in the expected future liquidity cost when selling (as buying more bonds increases both the chance of a cash shortfall next period, and the expected total bond liquidation transaction cost if there is a shortfall next period, whether c_t or Q_t or both are higher).

2.6 Market clearing

2.6.1 Final period: time $t+1$

The total net buying at time $t+1$ is given by:

$$
\begin{aligned}
Q_{t+1} &= \sum_f q^f_{t+1} && (18)\\
&= \sum_f \left(\frac{cash^f_t - f^f_{t+1}}{p_{t+1}}\right)^- && (19)\\
&= \frac{1}{v_{t+1} + c_{t+1}Q_{t+1}} \sum_f \left(cash^f_t - f^f_{t+1}\right)^- && (20)
\end{aligned}
$$

assuming the price is positive. This is equivalent to the following quadratic equation in Q_{t+1}:

$$c_{t+1}Q^2_{t+1} + v_{t+1}Q_{t+1} - \sum_f \left(cash^f_t - f^f_{t+1}\right)^- = 0 \tag{21}$$

whose solution is:

$$Q_{t+1} = \frac{-v_{t+1} + \sqrt{v^2_{t+1} + 4c_{t+1}\sum_f \left(cash^f_t - f^f_{t+1}\right)^-}}{2c_{t+1}} \leq 0 \tag{22}$$

Since individual funds are only selling or not trading, not buying, at time $t+1$, in aggregate they are also only selling or not buying, so $Q_{t+1} \leq 0$.

From the solution we see that there is a maximum total cash shortfall of $\frac{v^2_{t+1}}{4c_{t+1}}$ which can sustain an equilibrium: beyond that, the price pressure from selling makes the haircut so large that it doesn't generate enough cash to meet fund redemptions. For instance, if $v_{t+1} = \$100$ and $c_{t+1} = 5.6 \times 10^{-7}$ (calibrated from the pooled average haircut in the data), then the maximum total cash shortfall across funds that can be raised by selling the bond is \$4.5billion, which is very unlikely to be reached for an individual bond issue. But it could be more of a problem for bonds whose price is very sensitive to trading. This is one reason why, empirically, funds who hold multiple bonds do not concentrate their selling in a single bond to finance redemptions, as splitting the selling across multiple bonds would reduce the average haircut.

The price is positive if and only if $p_{t+1} \equiv v_{t+1} + c_{t+1} Q_{t+1} > 0$, so $Q_{t+1} > -\frac{v_{t+1}}{c_{t+1}} = \frac{-v_{t+1} - \sqrt{v_{t+1}^2}}{2c_{t+1}}$, which holds for both roots of the quadratic. Although theoretically there are 2 equilibria, with funds either selling a smaller quantity at a smaller haircut, or a larger quantity at a larger haircut, only one is plausible. For example, if $v_{t+1} = \$100$, $c_{t+1} = 5.6 \times 10^{-7}$, and the total cash shortfall across funds is \$100million, then (p_{t+1}, Q_{t+1}) can theoretically be (\$0.56, -180million units), but is much more plausibly (\$99.44, -1million units), with the bond's price close to its fundamental value. Choosing the solution the fund manager would optimally choose, where the haircut is smaller and therefore the AUM is larger, eliminates the negative root of the quadratic where the price is implausible.

Intuitively, the total number of units sold by funds $(-Q_{t+1})$ at time $t+1$ to cover any cash shortfall is:

- decreasing in the funds' fundamental value, as fewer units need to be sold if the price for each is higher;
- increasing in funds' total net outflows, as more units would need to be sold to cover fund outflows, due to a larger haircut;
- decreasing in funds' total cash, as fewer units would need to be sold to cover fund outflows if there is less of a cash shortfall.

The haircut as a percentage of the bond's fundamental value is:

$$-\frac{c_{t+1} Q_{t+1}}{v_{t+1}} = \frac{1 - \sqrt{1 + 4c_{t+1}/v_{t+1}^2 \sum_f \left(cash_t^f - f_{t+1}^f \right)^-}}{2} \geq 0 \tag{23}$$

2.6.2 First period: time t

The total net buying at time t is given by:

$$\begin{aligned} Q_t &= \sum_f q_t^f & (24) \\ &= \sum_f \frac{E_t[v_{t+1}/p_t] - 1 - 2\lambda_t^f p_t bonds_{t-1}^f - \frac{1}{\bar{f}^f - \underline{f}^f}\left(cash_{t-1}^f - f_t^f - \bar{f}^f\right) E_t\left[\frac{c_{t+1}Q_{t+1}}{p_{t+1}}\right]}{p_t\left(2\lambda_t^f p_t - \frac{1}{\bar{f}^f - \underline{f}^f} E_t\left[\frac{c_{t+1}Q_{t+1}}{p_{t+1}}\right]\right)} & (25) \end{aligned}$$

If the funds are homogeneous along the following dimensions: $\lambda_t^f = \lambda_t$, $\bar{f}^f = \bar{f}$, $\underline{f}^f = \underline{f}$, the expected return (from traded price p_t at time t to fundamental value v_{t+1} at time $t+1$) becomes:

$$\begin{aligned} E_t\left[\frac{v_{t+1}}{p_t}\right] - 1 &= 2\lambda_t p_t \sum_f bonds_{t-1}^f + \frac{1}{\bar{f} - \underline{f}} E_t\left[\frac{c_{t+1}Q_{t+1}}{p_{t+1}}\right] \sum_f \left(cash_{t-1}^f - f_t^f - \bar{f}\right) \\ &\quad + Q_t p_t \left(2\lambda_t p_t - \frac{1}{\bar{f} - \underline{f}} E_t\left[\frac{c_{t+1}Q_{t+1}}{p_{t+1}}\right]\right) & (26) \end{aligned}$$

So the bond's expected return is:

- increasing in the bond's risk;
- decreasing in funds' total cash;
- increasing in funds' total expected future outflows and cash shortfall;
- positively correlated with aggregate net buying.

The haircut at time t is:

$$\frac{c_t Q_t}{p_t} = c_t \sum_f \frac{E_t[v_{t+1}/p_t] - 1 - 2\lambda_t p_t bonds_{t-1}^f - \frac{1}{\bar{f} - \underline{f}}\left(cash_{t-1}^f - f_t - \bar{f}\right) E_t\left[\frac{c_{t+1}Q_{t+1}}{p_{t+1}}\right]}{p_t^2\left(2\lambda_t p_t - \frac{1}{\bar{f} - \underline{f}} E_t\left[\frac{c_{t+1}Q_{t+1}}{p_{t+1}}\right]\right)} \qquad (27)$$

2.7 Liquidity value-at-risk

A fund's expected total liquidity cost given a cash shortfall from high fund outflows can be computed by conditioning on whether there is a cash shortfall:

$$
\begin{aligned}
E_t\left[\text{total haircut}\right] &= P_t[\text{cash shortfall}]E_t\left[(\text{haircut per unit}) \times (\text{units sold})\,|\text{shortfall}\right] && (28)\\
&= P_t[f_{t+1} > cash_t]E_t\left[(\text{haircut per unit}) \times \frac{\text{shortfall}}{p_{t+1}}\right] && (29)\\
&= \left(\frac{\bar{f} - cash_t}{\bar{f} - \underline{f}}\right) E_t\left[c_{t+1}Q_{t+1}\left(\frac{(f_{t+1} - cash_t)^+}{v_{t+1} + c_{t+1}Q_{t+1}}\right)\right] && (30)\\
&\approx \left(\frac{\bar{f} - cash_t}{\bar{f} - \underline{f}}\right) E_t\left[\frac{c_{t+1}Q_{t+1}}{v_{t+1}}(f_{t+1} - cash_t)^+\right] && (31)
\end{aligned}
$$

3 Data

Data on bond liquidity costs, credit ratings, and trade volume are from TRACE / Mergent FISD on WRDS. Data on bond mutual funds' holdings is from Morningstar. We exclude ultra-short-term and index funds, so we focus only on active long-term open-end corporate bond US mutual funds. As a sanity check, total net assets and the sum of the market value of holdings should be identical. So if the magnitude of the difference between the total net assets and the sum of the market value of holdings is greater than 18% (the 90th percentile), we remove the fund from the sample.

3.1 Cash

The computation of cash from Morningstar is delicate, and requires some thought and re-categorization. In months where a fund holds derivatives, but no cash-derivatives, we reclassify cash and cash-currency as cash-derivatives. Also reclassified as cash-derivatives are items originally classified as cash or cash-currency which include the names 'offset', 'broker', 'margin', 'ccp', 'fut', 'unsettled', 'der', 'otc', 'future", 'haircut', 'rrp', 'swap', 'collateral', 'cme', 'deriv', 'call', 'put', or 'committed'. Holdings which are themselves mutual funds are interpreted as money-market mutual funds and are reclassified as cash if they include the following in their name: 'fidelity revere str tr', 'goldman sachs fs government instl', 'liquidity', 'fedfund', 'mm fds', 'lqudty', 'mmkt', 'government obligs', 'money market', 'cash mgmt', 'cash', 'obl', 'govtt rsrv', 'treasury bd', 'short', 'shrt-trm', 'gov. reserve', or 'liquid'.

3.2 Derivatives

Contrary to traditional thoughts on mutual funds, many hold derivatives as part of their portfolio. Data on funds' derivative holdings is from SEC filings via form N-PORT. There are 6 asset categories (commodity, credit, equity, foreign exchange, interest rate, and other), and for each there are 7 derivative instrument categories (forward, future, option, swap, swaption, warrant, other), which we aggregate.

For derivatives we focus on the period July 2019 to June 2020, which covers the pre-Covid period up to and including January 2020, the Covid outbreak which we classify as February-March 2020, and the market recovery from April 2020 onwards. Funds are classified as 'hedging' or 'amplifying' based on the correlation between their derivative and non-derivative returns in the pre-Covid period. Following Kaniel and Wang (2021) we compute funds' derivative-induced return (DIR) as:

$$DIR = \frac{\text{realized gain + unrealized appreciation - lag(unrealized appreciation)}}{\text{lag(TNA)}} \tag{32}$$

The residual non-derivative induced return (non-DIR) is computed by subtracting the DIR from the total fund return.

4 Empirical analysis

We see from Figure 2 that the correlation between funds' returns from derivatives and non-derivative holdings is highly skewed, with many funds having a large negative correlation. The mean and median correlations are -0.15 and -0.19, respectively. We rank funds with at least 3 returns in their time-series by this correlation in the pre-Covid period, and classify funds which hold at least one derivative at at least one point in time as either 'hedging' (the lowest / most negative correlation tercile) or 'amplifying' (the highest correlation tercile), following Kaniel and Wang (2021) who analyse equity mutual funds. The distribution of correlations is quite different between bond and equity mutual funds; for bond funds it is much skewed more towards negative correlations, whereas Kaniel and Wang (2021) show that for equity funds it is much more symmetrical. Our cut-off correlation values for hedging and amplifying are negative (-0.55) and positive (0.10), respectively, so this classification allows the interpretation that hedging funds are typically using derivatives to de-lever their portfolio returns, while amplifying funds are using them more to lever up.

The classification of funds is corroborated by looking at the market beta of fund returns in Table 4. We regress fund returns for hedging, amplifying, and no-derivative funds on the Vanguard Total Bond Market Index. We see that the beta is lowest for hedging funds (0.57), highest for amplifying funds (0.90), and in between for no-derivative funds (0.78). All the betas are less than one, so all three groups have less systematic risk than the benchmark index. Only the hedging fund group has a significant alpha, which is around +11 basis points per month. Table 5 shows that expense ratios are higher for hedging funds than amplifying funds on average, but their total net assets are lower.

4.1 Summary statistics

Summary statistics are provided in Table 1 (whole sample), Table 2 (Global Financial Crisis of September 2008), and Table 3 (Covid outbreak of March 2020). We see that the outbreak of Covid-19 was an even more severe period than the Financial Crisis across a number of dimensions. The median liquidity cost jumped from 19 basis points across all time periods to 46 basis points in September 2008 during the Financial Crisis and 49 basis points at the start of the Covid-19 outbreak in March 2020. Bond returns were typically positive overall, with a median monthly return of 0.42%, but with a large cross-sectional standard deviation of 4.3%, and became very negative and more variable in the crisis periods, with median returns of -3.44% and -5.39%, and standard deviations of 8.3% and 11.08%, for the GFC and Covid-19 outbreak periods, respectively. Fund flows were close to zero overall, but become negative in the crisis periods, with medians of -1.12% and -3.25% at the starts of the GFC and Covid-19, respectively.

4.2 Holdings

Table A1 shows the mean proportion of mutual fund holdings in different asset classes for funds whose derivative positions amplify or hedge their portfolio returns, and for funds who never hold derivatives, averaged across quarterly data. Figure 3 plots the proportion of mutual fund holdings in cash, government bonds, corporate bonds, and derivatives before, during, and after the outbreak of Covid-19 in February/March 2020.

4.2.1 Cash

Figure 3 shows that on average hedging funds held a lower proportion of cash than amplifying funds in all time periods. The proportion of cash dropped for both types of funds from March 2020 onwards to finance investor redemptions. For hedging funds, the drop in cash began a month earlier, in February 2020. Pre-Covid, the funds with no derivatives held a proportion of cash in between the hedging and amplifying funds on average, but it didn't drop much after the onset of Covid, and since March 2020 was higher than the funds which held derivatives. But Table A1 shows that there is a lot of cross-sectional variation between funds in all three fund strategies, with the cross-sectional standard deviation more than double the averages in all cases.

4.2.2 Government and Corporate Bonds

Hedging funds held a much larger proportion of their portfolios in corporate bonds than amplifying funds, but a lower proportion in government bonds. Since corporate bonds are almost always riskier than government bonds in the US, this suggests how different fund types use different derivative strategies to control the market risk of their portfolios, with hedging funds using derivatives to reduce the risk of their riskier bond holdings, and amplifying funds using derivatives to increase the risk of their less risky bond holdings.

4.2.3 Derivatives and Cash-Derivatives

Both hedging and amplifying funds held long positions in derivatives on average during the time period, but hedging funds held larger positions. With similar levels pre-Covid, amplifying funds reduced their average net long positions slightly afterwards, whereas hedging funds increased them in February and March 2020, before switching to a large negative average position in the recovery period. This highlights that derivative strategies are not static, and the classification of whether funds are hedging and amplifying may be time-varying. The cross-sectional variation in derivatives was much higher for hedging funds than amplifying funds, particularly during the recovery period.

'Cash-derivatives' denotes cash specifically set aside for funds' derivative holdings, so its sign is typically the opposite of that for their derivative holdings, with correlated magnitude. For instance, in unreported results, for hedging funds, as their long derivatives position increased at the start of the Covid outbreak and then they went short in large size in the recovery period, so their cash-derivatives went from small and negative to large and positive in the recovery period.

4.3 Fund flows and probability of a cash shortfall

Table 5 shows that amplifying funds had higher, but more volatile, net fund inflows than hedging funds. In unreported results, this was consistent across all periods.

Equation (28) from the model show that the probability of a cash shortfall due to investor outflows affects funds' trading and the liquidity-value-at-risk, respectively. In the model we assumed that fund flows had a uniform distribution to be able to solve it in closed form. But empirically we see from Figure 4 that the distribution pooled across all funds and all time is closer to normally distributed, though with excess kurtosis. The t-stat is a useful heuristic for estimating the probability of a cash shortfall after paying out redemptions, and if we approximate the distribution of fund flows as normal, then we can estimate the implied probability of a fund having a cash shortfall as:

$$
\begin{aligned}
P_t\,[\text{cash shortfall at time } t+1] &\equiv P_t\,[cash_t < f_{t+1}] \qquad (33)\\
&= P_t\left[\frac{cash_t - E_t[f_{t+1}]}{SD_t[f_{t+1}]} < \frac{f_{t+1} - E_t[f_{t+1}]}{SD_t[f_{t+1}]}\right] \qquad (34)\\
&\approx 1 - \Phi\left(\frac{cash_t - E_t[f_{t+1}]}{SD_t[f_{t+1}]}\right) \qquad (35)
\end{aligned}
$$

For the hedging and amplifying funds, in both the pre-Covid and recovery periods, the sum of mean cash holdings and mean net fund inflows are quite a different number of fund flow standard deviations above zero, so there is a lot of variation in the probability of a cash shortfall. In the pre-Covid period the t-stat for amplifying funds = (3+1.267)/5.641 = 0.74, corresponding to a 22% probability of a cash shortfall, and the t-stat for hedging funds = (1.3-0.491)/2.856 = 1.20, corresponding to a 39% probability of a cash shortfall. In the recovery period the t-stat for amplifying funds = (1.2+2.124)/7.623 = 0.68, corresponding to a 33% probability of a cash shortfall, and the t-stat for hedging funds = (-0.6+0.431)/5.06 = 0.75, corresponding to a 51% probability of a cash shortfall. These computed probabilities are only part of the picture of funds' liquidity risk management, as the market risk and liquidity risk are different across fund types and across time, and there is likely a fund-specific component to the conditional distributions of fund flows. Since hedging funds have less systematic bond market risk, they may be more comfortable with a higher cash shortfall probability, if ex ante they may have felt that their fund returns were somewhat protected on the downside and so they were somewhat insulated from fund outflows when the market fell, although ex post this was not the case.

Figure 5 plots the expected portfolio liquidation cost as a function of a fund's proportion of cash and the bond's liquidity cost, assuming that investor fund flows are normally distributed with the same mean and standard deviation as those for funds which never hold derivatives. The vertical lines mark the mean proportion of cash for a no-derivative fund, and a 95% confidence interval for cash, to give a sense of where funds are likely to operate. Intuitively, we see that the higher the cash position, the lower the expected liquidation cost, as both the probability of a cash shortfall, and the magnitude of liquidation cost given a shortfall, are lower. The higher the bond transaction cost, the higher the expected liquidation cost as a proportion of AUM, but the magnitude is much smaller, as only a portion of the portfolio needs to be liquidated.

4.4 Trading, liquidity, and bond returns

4.4.1 Bond trading

A prediction from the model is that funds' trading, in the final period most starkly, is affected by the cash shortfall that they face in meeting their investors' redemption needs. In the final period of the model, they use up all their liquid cash first, before selling the less liquid bond, which comes with transaction costs, so the model imposes a pecking order of selling in order of liquidity by assumption. More generally, funds may not want to completely empty their cash reserves, but we expect to see their trading explained to some extent at least by a pecking order from cash to corporate bonds when they have investor outflows.

Table 7 shows that mutual funds' corporate bond trading is positively correlated with fund flows, but less so when their cash holding is larger. We regress corporate bond trading, at the bond level, measured by the percentage increase in the number of units held from one month to the next, on a number of factors predicted by the theoretical model. We include monthly fixed effects and standard errors are clustered at the fund level. We see that trading is positively and significantly related to fund flows, i.e. higher net outflows are at least partly financed by selling larger quantities of corporate bonds, and higher net inflows lead to more corporate bond buying. Buying is negatively and significantly related to the interaction of fund outflows with cash, i.e. there is even more selling of corporate bonds when a funds' cash reserves are low, because it becomes more necessary to finance those fund outflows by selling corporate bonds, rather than just using cash reserves. We see that cash only significantly affects selling when it is interacted with outflows, so for instance low cash is only a concern for funds, and influences their trading, if outflows are simultaneously relatively high.

The illiquidity of the security, and its interaction with fund flows, do not significantly affect trading, but this may be because it is correlated with the bond's interest rate risk and credit risk, proxied by the bond's duration and an indicator for whether the bond is investment grade or high yield, respectively. Duration is also not a significant predictor of trading, but investment grade bonds are sold more (or bought less) than high yield bonds, both for the outflows and inflows samples.

Table 8 splits the outflows sample into amplifying funds, hedging funds, and funds with no derivative holdings. We see that amplifying funds' trading is significantly correlated with the interaction of fund flows with cash, while hedging funds' trading is significantly correlated with the interaction of fund flows with bonds' illiquidity. This is intuitive because amplifying funds typically hold more cash in reserve to satisfy investor outflows, whereas hedging funds hold less cash, and so are more likely to have to liquidate bonds to satisfy investor outflows. Amplifying funds' corporate bond trading is less sensitive to flows when cash is high, and hedging funds' corporate bond trading is less sensitive to flows when the bonds are more illiquid.

Table 9 shows that mutual funds' government bond trading is also positively correlated with fund flows, but now the interaction of flows with cash is insignificant. This may be that when fund flows are negative, it's a time when funds not only need to raise cash but also want to reduce the market risk of their portfolio, and so trading corporate bonds rather than government bonds is a way to combine both. Duration is significant and positive, as government bonds' market risk is dominated by interest rate risk rather than credit risk. The greater the duration, the more the government bond is sold if there is a fund outflow, so funds are not just funding their outflows by liquidating government bonds, but simultaneously reducing the risk of their portfolios. For inflows, the greater the duration, the more the government bond is bought if there is a fund inflow, so funds are simultaneously increasing the risk of their portfolios.

Table 10 digs deeper into the interaction of cash and investor fund flows. It highlights the pecking order from cash to corporate bonds in the event of liquidation, depending on the magnitude of fund flows as a percentage of cash reserves. We separately regress corporate bond trading and cash trading on fund flows, stratified by what proportion those flows represent in terms of funds' cash reserves. It shows that bond (cash) trading is much more (less) sensitive to fund flows when redemptions are large relative to cash. The statistical significance of these results is correlated with their magnitudes, with larger (smaller) t-statistics for bond (cash) trading when fund flows are larger.

4.4.2 Liquidity costs

In the model the price is assumed to be $p_t = v_t + c_t Q_t$, where v_t is the bond's fundamental value, and its liquidity cost $c_t Q_t$ is the product of a non-trading component c_t and aggregate trading (Q_t is negative for net selling). This highlights the role of price pressure, motivated by e.g. the model in Randall (2021b) where dealers in an OTC market have limited risk-bearing capacity/tolerance, and so if they are at their optimal inventory level, to trade in larger size they require compensation for the extra risk that involves in the corporate bond market where they may not be able to offload those trades for several days, particularly a concern for them when the bonds have high credit risk, and in crisis periods when they have tighter market risk and capital limits.

Figure 6 shows that liquidity costs, and the change in liquidity costs, spiked in the GFC and Covid-19 periods. The level was higher in the GFC, but the change was higher at the outbreak of Covid-19.

In Table 11 we regress liquidity costs on aggregate trading, aggregate cash shortfall, measures of bond trading frequency, trade volume, and bond risk. Liquidity costs are measured as the difference between the average price that customers buy from, and sell to, a dealer within a month, divided by two, for each bond. This is an estimate for the average 'markup' from the dealer to the customer.

Bond trading frequency is proxied by the amount of the bond still outstanding since issuance, and the log of dollar trade volume. Bond risk is proxied by lagged duration to measure interest rate risk, and an investment grade credit rating dummy to measure credit risk. We include monthly fixed effects, and standard errors are also clustered at the monthly level. The table shows that corporate bonds' liquidity costs increase when funds are on average selling that security. The effect of funds' trading on liquidity costs are an order of magnitude larger at the Covid-19 onset in March 2020, and even stronger in the Financial Crisis in September 2008.

The results are even stronger in the tumultuous periods of the financial crisis and the outbreak of Covid-19, when bond dealers had less risk appetite and capacity, and raised the cost of trading. Only during Covid-19 is funds' mean cash shortfall statistically significant, with a higher average shortfall increasing liquidity costs. While the necessity of selling bonds to meet investor redemptions when there is a cash shortfall may be the same as a more normal market period, the capacity of dealers to absorb inventory in the crisis times was lower.

Table 12 shows that changes in corporate bonds' liquidity costs are also negatively related to funds' trading. As with the level of liquidity costs, the change in liquidity costs is only significantly affected by funds' cash shortfall in the Covid-19 period.

The significance of aggregate trading and aggregate cash shortfall highlights the systemic importance of bond mutual funds in the corporate bond market, with funds needing to account for the holdings and trading of their peers.

4.4.3 Corporate bond returns

Figure 6 shows corporate bond returns over time, with particularly large negative returns in the crisis periods of the GFC and the outbreak of Covid-19.

In unreported results, in the pre-Covid period bond returns are quite similar across the three fund groups, at around 60 basis points per month. But amplifying funds fared much better than hedging funds at the start of the Covid outbreak (+0.47% versus -0.55% in February 2020, and

-6.67% versus -9.57% in March 2020), while hedging funds had higher returns in the recovery period (+2.69% versus +2.31%). The mean return of funds (0.37% monthly) is very similar to that of their non-derivative holdings (0.39%), whereas that of the derivatives is only 0.0023%. However derivatives represent a much larger component of funds' return standard deviation: 1.2% monthly versus 3.07% for the non-derivatives, and 2.78% overall.

Table 12 shows that corporate bond returns are positively related to funds' trading in the full sample. This is related to equation (26) from the model on expected returns which predicted this result. The model also predicts that funds' cash shortfall should be negatively related to expected bond returns, which it is, but only significantly so in the Covid-19 period.

5 Conclusion

We show, both theoretically and empirically, that aggregate measures of mutual fund trading, and their cash reserves relative to fund flows are systemically important to corporate bond liquidity and expected returns. Funds have to consider not only their own cash position, expected fund flows, and unconditional liquidity costs, but the cash positions of the aggregate mutual fund industry, aggregate expected fund flows, and liquidity costs conditional on the aggregate trading of the market. The results are particularly strong in the large market downturn periods of the Global Financial Crisis and the outbreak of the Covid-19 pandemic.

We are also the first to analyze bond mutual funds' use of derivatives to hedge or amplify their returns, using funds' SEC filings. We document large variation in hedge fund strategies, with some funds using those derivatives to hedge their returns, some to amplify them, and many choosing not to use derivatives at all. It will be interesting to explore further the institutional reasons why there is such a diversity of strategy.

Our model builds our intuition on the trade-offs that mutual funds face when trading bonds: buying more bonds with cash increases expected portfolio return, but at the cost of greater market risk, and it increases both the probability of a future cash shortfall and the expected liquidation cost in the case of large investor redemption requests. We plan to develop the model further, by extending from cash and a single bond to many assets, including derivatives which can hedge or amplify both the risk and return of funds' portfolios, to further understand mutual funds' derivative strategies we have documented empirically.

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Figure 2: **Correlations between Derivative Returns and Non-Derivative Returns** This figure plots the cross-sectional distribution of correlations between monthly derivative returns and non-derivative returns between July 2019 and January 2020.

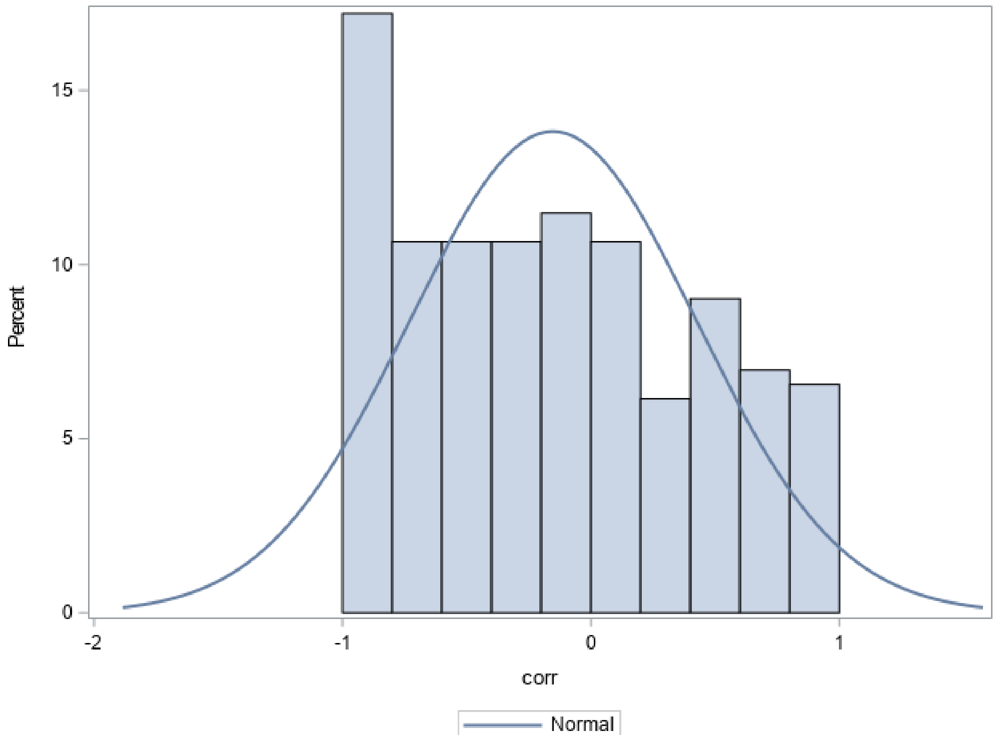
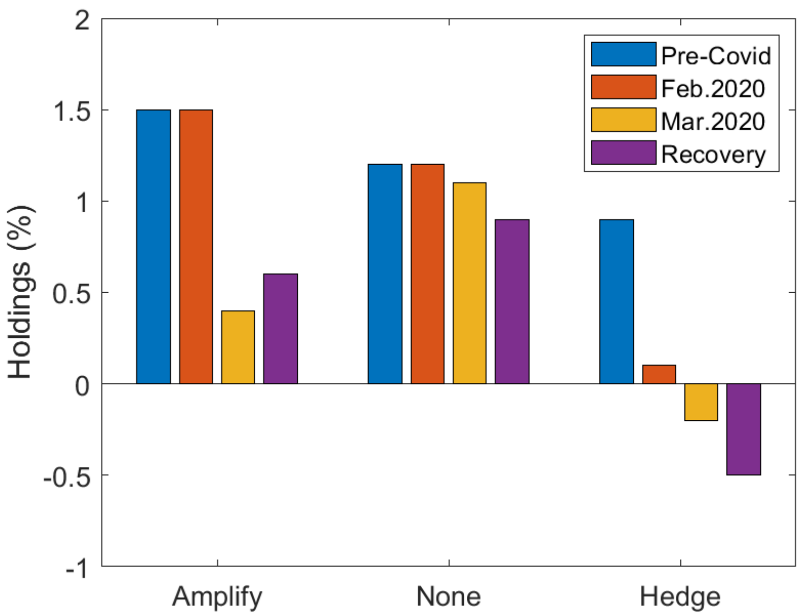


Figure 3: **Mutual Fund Holdings Around Covid-19.** This figure plots the proportion of mutual fund holdings in cash and government bonds before, during, and after the outbreak of Covid-19 in February/March 2020, for funds whose derivative positions amplify or hedge their portfolio returns, and for funds who never hold derivatives.

Panel A: Cash



Panel B: Government Bonds

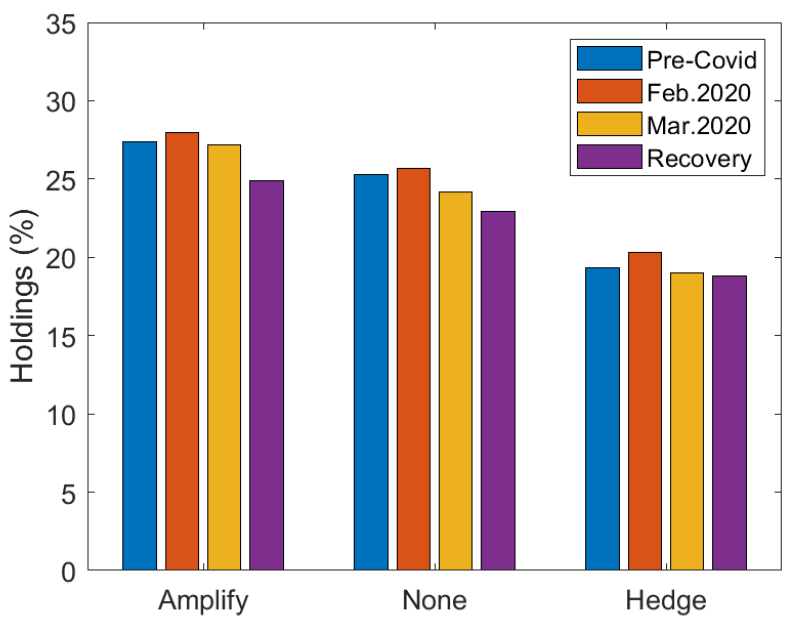
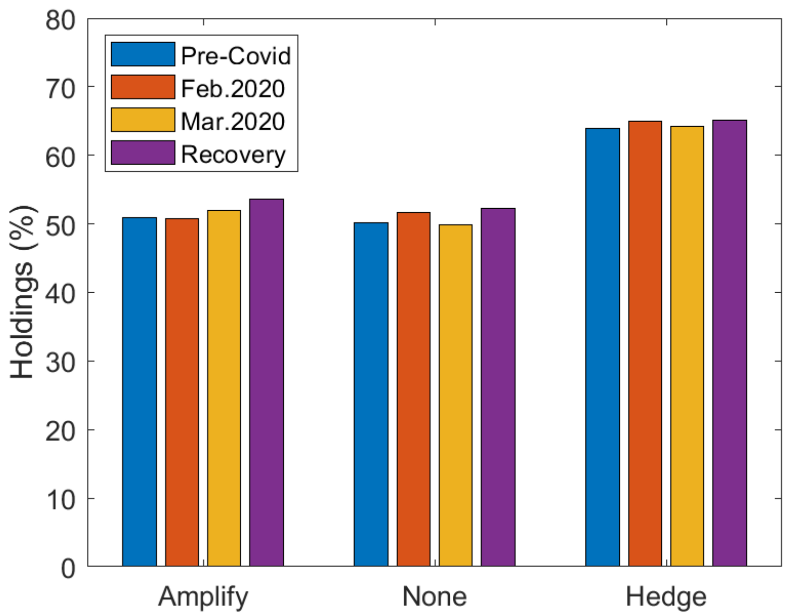


Figure 2 - Continued: **Mutual Fund Holdings Around Covid-19.** This figure plots the proportion of mutual fund holdings in corporate bonds and derivatives before, during, and after the outbreak of Covid-19 in February/March 2020, for funds whose derivative positions amplify or hedge their portfolio returns, and for funds who never hold derivatives.

Panel C: Corporate Bonds



Panel D: Derivatives

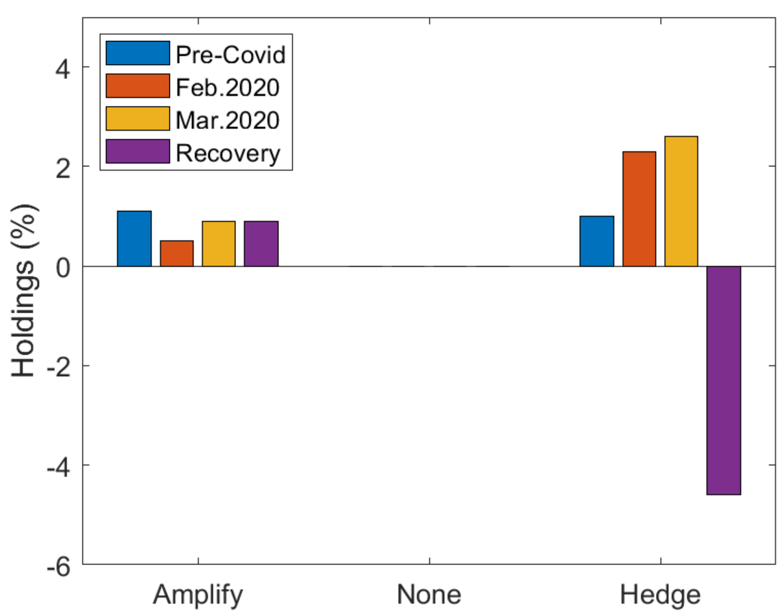


Figure 4: **Distribution of Fund Flows Pooled Across Funds Over Time.** This figure plots the distribution of fund flows pooled across funds and time between January 2005 and June 2020. For comparison, a normal distribution of best fit is overlaid, to show that the distribution of fund flows has excess kurtosis.

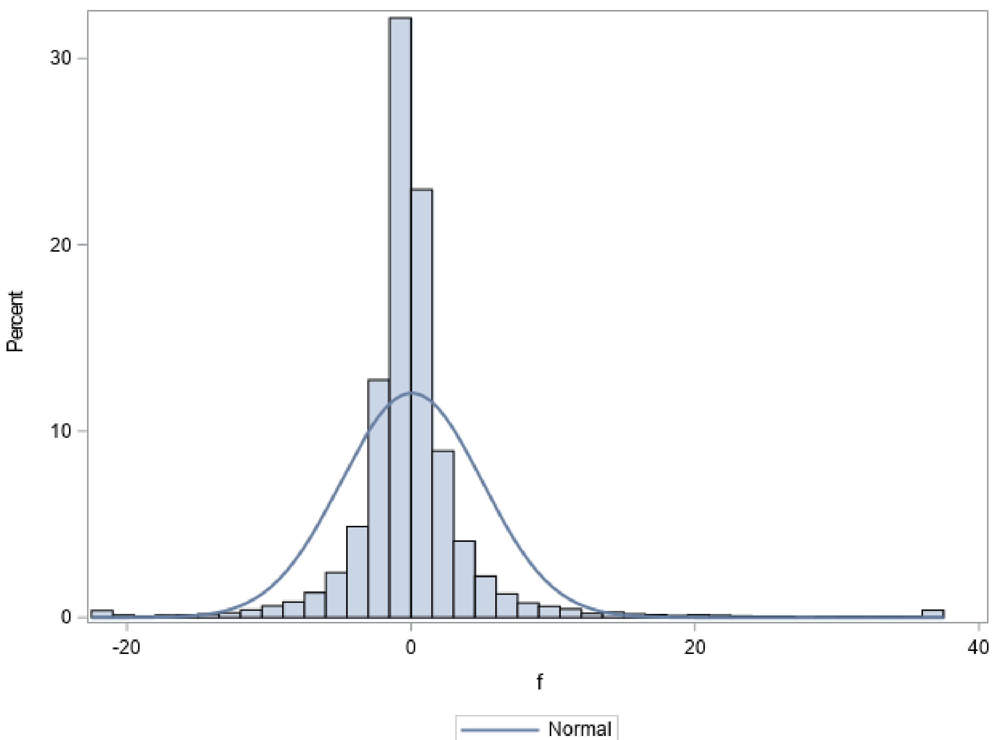


Figure 5: **Expected liquidation cost for no-derivative funds.** This figure plots the expected portfolio liquidation cost as a function of a fund's proportion of cash and the bond's liquidity cost, assuming that investor fund flows are normally distributed with the same mean and standard deviation as those for funds which never hold derivatives. The vertical lines mark the mean proportion of cash for a no-derivative fund, and a 95% confidence interval for cash.

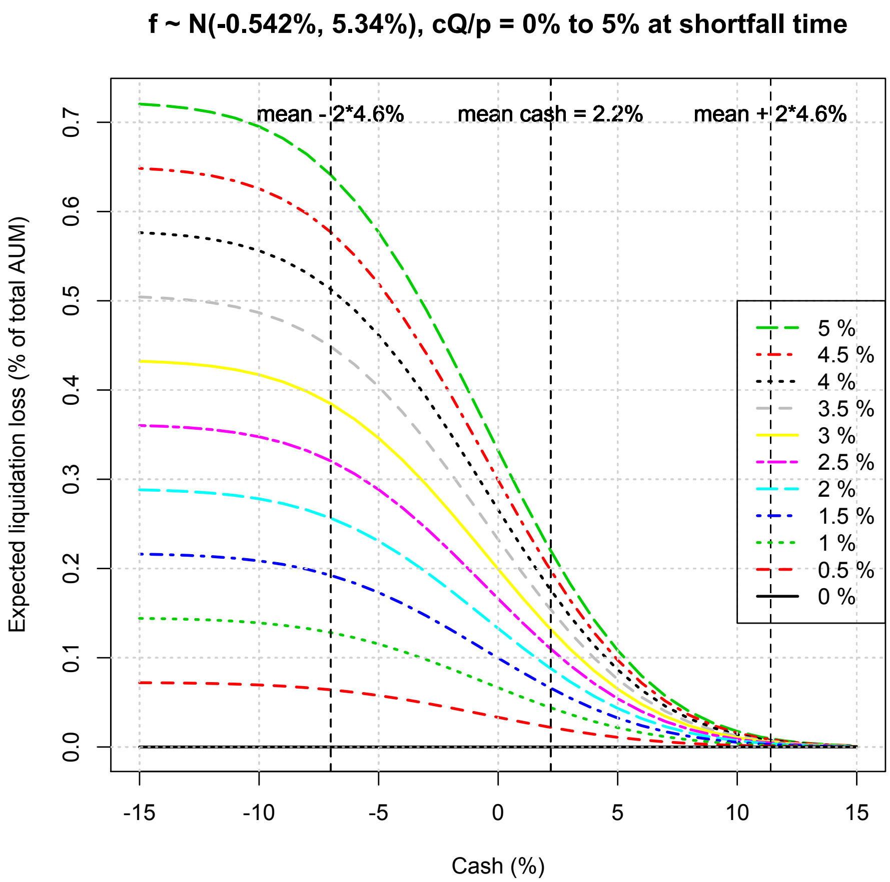
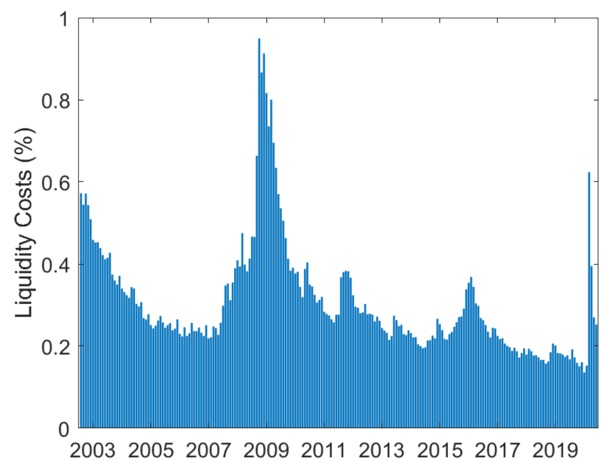
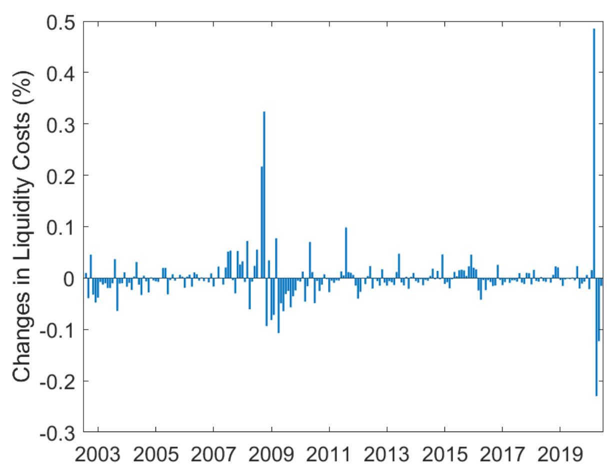


Figure 6: **Asset Prices Over Time.** This figure plots liquidity costs, the change in liquidity costs, and corporate bond returns in the top, middle and bottom panels, respectively. Liquidity costs are measured as half the difference between the mean prices at which customers buy from, and sell to, dealers in each month. Corporate bond returns are a weighted average of individual bond returns held by mutual funds in each month.

Panel A: Liquidity Costs



Panel B: Changes in Liquidity Costs



Panel C: Corporate Bond Returns

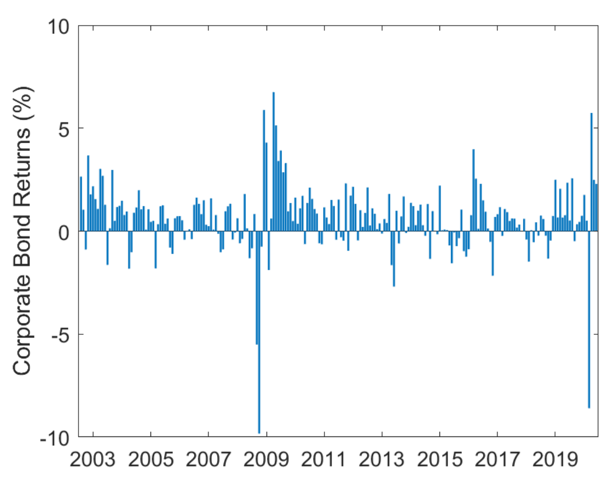


Figure 7: **Haircut % at time $t+1$.** This figure plots the percentage haircut at time $t+1$ for 2 equilibria, in the top and bottom rows, as a function of the bond's fundamental value (v_{t+1}), liquidity cost sensitivity to trading (c_{t+1}), and cash shortfall ($cash_t - flows_{t+1}$). Default calibration: $v_{t+1} = \$100$, cash shortfall = \$100 million, $c_{t+1} = 5.6 \times 10^{-7}$.

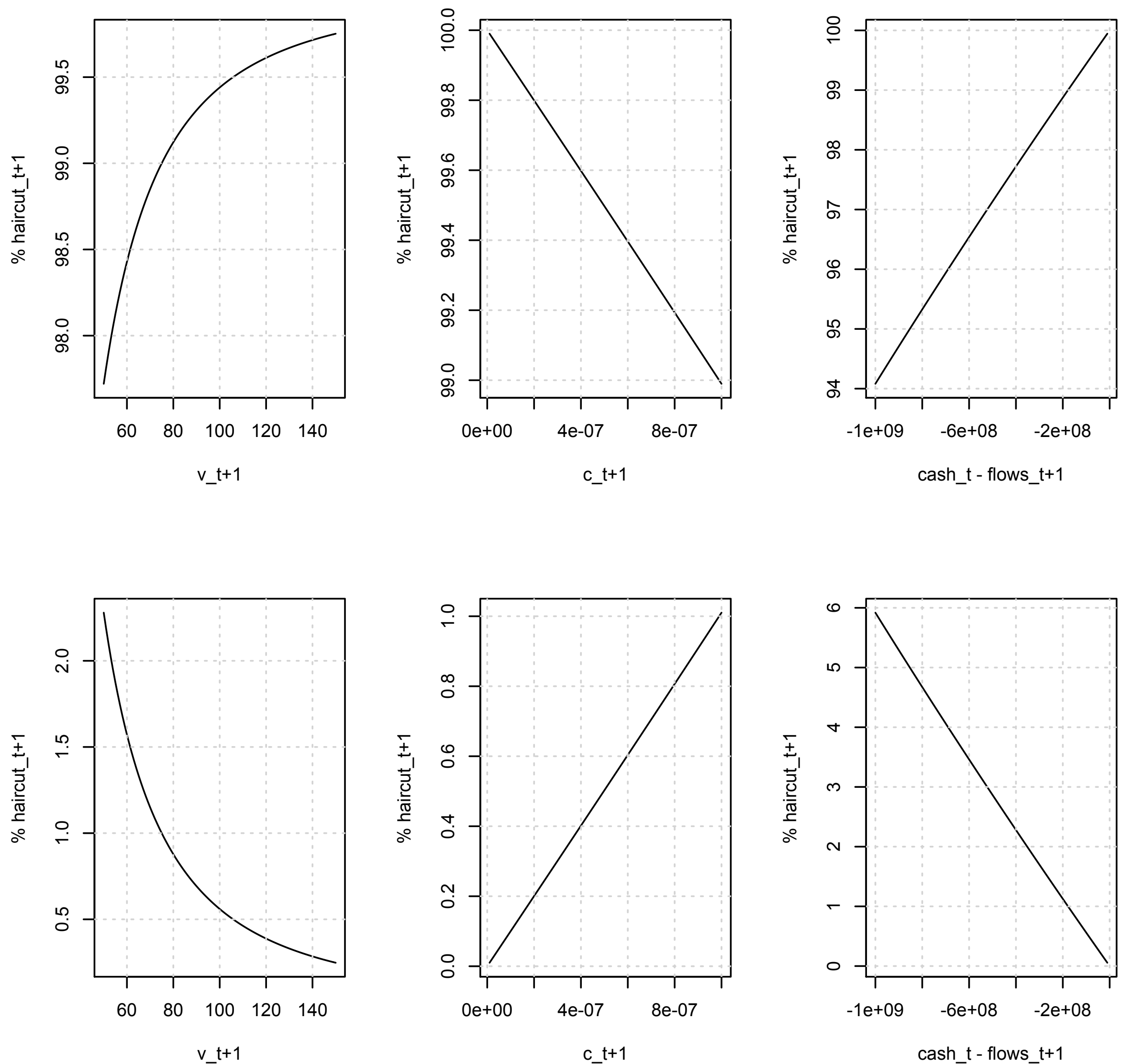


Figure 8: **Aggregate trading at time** $t+1$**.** This figure plots aggregate net buying at time $t+1$ (Q_{t+1}) for 2 equilibria, in the top and bottom rows, as a function of the bond's fundamental value (v_{t+1}), liquidity cost sensitivity to trading (c_{t+1}), and cash shortfall ($cash_t - flows_{t+1}$). Default calibration: $v_{t+1} = \$100$, cash shortfall = \$100 million, $c_{t+1} = 5.6 \times 10^{-7}$.

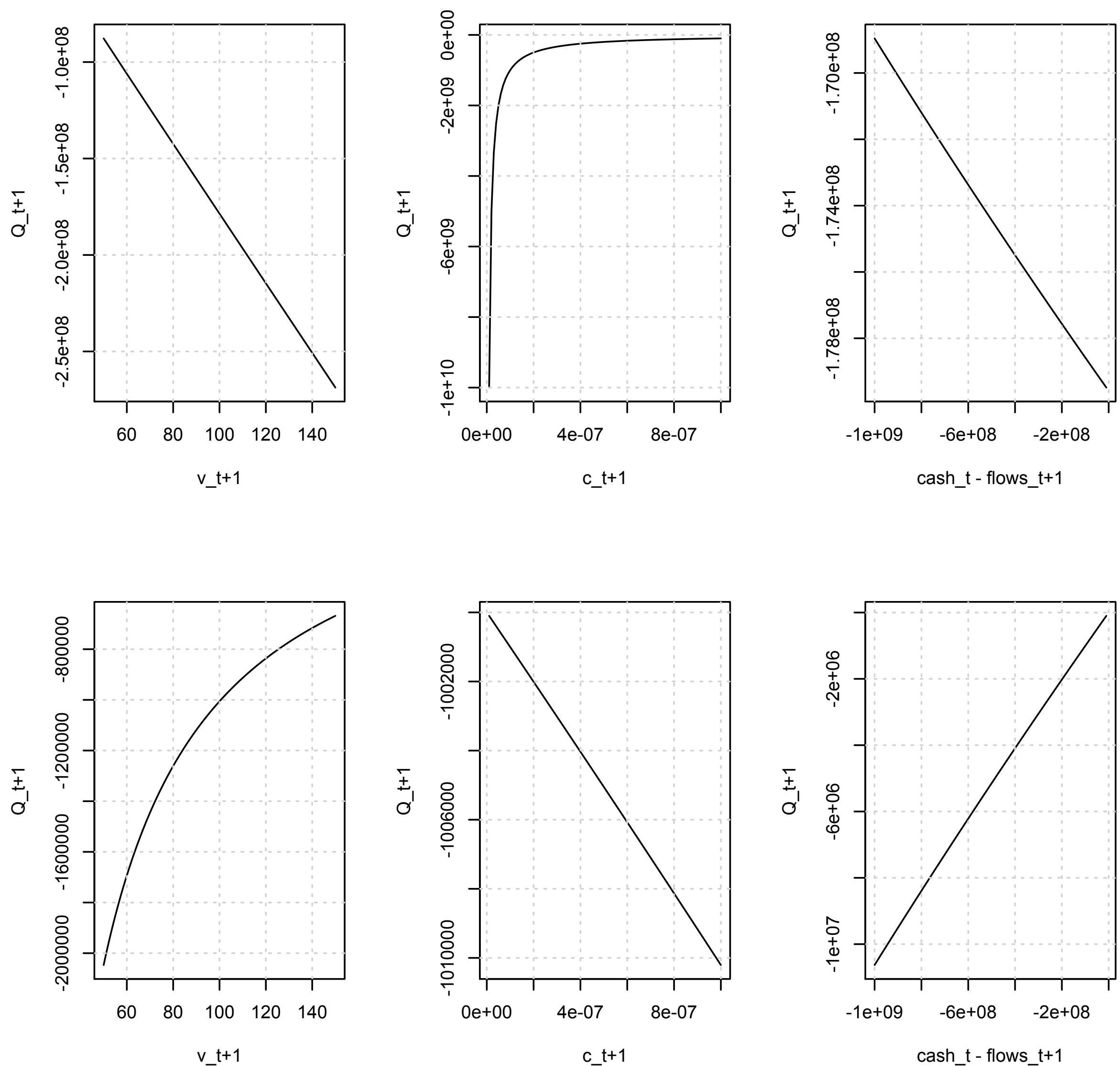


Table 1: **Summary Statistics.** This table shows summary statistics for key variables. c denotes liquidity costs measured as the mean difference between prices when customers are buying and selling within a month, divided by two. Δc is the change in those liquidity costs. 1{IG} is an indicator variable, equal to 1 if the bond's credit rating is investment grade, and 0 if it's high yield. Duration is the bond's duration, as a measure of interest rate risk. Aggregate Mean Trade is the percentage increase in funds' bond holding (in number of shares) averaged across all funds. Aggregate Cash Shortfall is the difference between investor flows and funds' cash reserves, i.e. cash minus outflows, averaged across all funds. Outstanding denotes the amount of the bond issue still outstanding in US dollars. $Volume denotes the total monthly trading volume in millions of dollars. Fund Flows denote investor fund flows in percent. Fund Cash/TNA denotes the ratio of funds' cash to total net assets.

Variables	#Obs.	Mean	Std. Dev.	P10	P25	P50	P75	P90
c	977982	0.29	0.33	0.05	0.10	0.19	0.36	0.63
Δc	894802	0	0.29	-0.23	-0.08	0	0.08	0.23
Bond Returns	1034420	0.58	4.30	-1.88	-0.37	0.42	1.53	3.28
1{IG}	1027232	0.75	0.43	0	0	1	1	1
Duration	1064358	6.06	4.14	1.75	3.08	4.96	7.58	12.96
Aggregate Mean Trade	953849	0.31	7.25	-1.09	0	0	0	1.01
Aggregate Cash Shortfall	1291274	4.36	5.76	-0.45	1.31	3.37	6.14	10.49
Log(Outstanding)	1072073	13.09	0.79	12.21	12.61	13.12	13.53	14.12
Log($Volume)	1072716	16.57	1.98	13.94	15.54	16.86	17.9	18.74
Fund Flows	39065	0.01	5.25	-3.55	-1.52	-0.27	1.03	3.49
Fund Cash/TNA	32299	4.82	6.54	0.47	1.40	3.08	5.95	11.16

Table 2: **Summary Statistics - GFC.** This table shows summary statistics for key variables in the Global Financial Crisis of September 2008. c denotes liquidity costs measured as the mean difference between prices when customers are buying and selling within a month, divided by two. Δc is the change in those liquidity costs. 1{IG} is an indicator variable, equal to 1 if the bond's credit rating is investment grade, and 0 if it's high yield. Duration is the bond's duration, as a measure of interest rate risk. Aggregate Mean Trade is the percentage increase in funds' bond holding (in number of shares) averaged across all funds. Aggregate Cash Shortfall is the difference between investor flows and funds' cash reserves, i.e. cash minus outflows, averaged across all funds. Outstanding denotes the amount of the bond issue still outstanding in US dollars. $Volume denotes the total monthly trading volume in millions of dollars. Fund Flows denote investor fund flows in percent. Fund Cash/TNA denotes the ratio of funds' cash to total net assets.

Variables	#Obs.	Mean	Std. Dev.	P10	P25	P50	P75	P90
c	3362	0.66	0.62	0.09	0.21	0.46	0.89	1.55
Δc	2887	0.22	0.59	-0.33	-0.06	0.13	0.44	0.93
Bond Returns	3865	-5.51	8.30	-14.4	-7.44	-3.44	-0.79	0.91
1{IG}	3985	0.70	0.46	0	0	1	1	1
Duration	4080	5.20	3.14	1.77	2.92	4.43	6.63	10.64
Aggregate Mean Trade	3122	0.30	6.70	0	0	0	0	0
Aggregate Cash Shortfall	4255	5.55	7.37	-0.72	0.9	3.69	8.05	15.81
Log(Outstanding)	4094	12.96	0.79	12.07	12.43	12.9	13.46	13.96
Log($Volume)	4095	15.82	2.33	12.32	14.49	16.32	17.49	18.34
Fund Flows	203	-1.09	5.83	-4.26	-2.44	-1.12	-0.02	1.20
Fund Cash/TNA	181	6.98	8.04	0.62	2.01	4.26	10.28	16.19

Table 3: **Summary Statistics - Covid-19.** This table shows summary statistics for key variables at the start of the Covid outbreak in March 2020. c denotes liquidity costs measured as the mean difference between prices when customers are buying and selling within a month, divided by two. Δc is the change in those liquidity costs. $1\{\text{IG}\}$ is an indicator variable, equal to 1 if the bond's credit rating is investment grade, and 0 if it's high yield. Duration is the bond's duration, as a measure of interest rate risk. Aggregate Mean Trade is the percentage increase in funds' bond holding (in number of shares) averaged across all funds. Aggregate Cash Shortfall is the difference between investor flows and funds' cash reserves, i.e. cash minus outflows, averaged across all funds. Outstanding denotes the amount of the bond issue still outstanding in US dollars. $Volume denotes the total monthly trading volume in millions of dollars. Fund Flows denote investor fund flows in percent. Fund Cash/TNA denotes the ratio of funds' cash to total net assets.

Variables	#Obs.	Mean	Std. Dev.	P10	P25	P50	P75	P90
c	6617	0.62	0.52	0.12	0.27	0.49	0.82	1.29
Δc	6148	0.49	0.49	0.01	0.18	0.38	0.67	1.10
Bond Returns	6579	-8.60	11.08	-19.53	-10.77	-5.39	-2.03	-0.43
$1\{\text{IG}\}$	6127	0.85	0.36	0	1	1	1	1
Duration	6667	7.06	5.16	1.63	2.95	5.49	10.82	15.57
Aggregate Mean Trade	5885	0.07	7.89	-3.03	0	0	0	1.07
Aggregate Cash Shortfall	9435	-0.24	6.86	-5.76	-3.81	-1.27	0.92	7.13
Log(Outstanding)	6833	13.32	0.71	12.60	12.90	13.29	13.82	14.22
Log($Volume)	6834	16.99	1.98	14.36	15.95	17.22	18.30	19.20
Fund Flows	426	-3.12	7.26	-9.77	-6.13	-3.25	-1.01	1.56
Fund Cash/TNA	336	3.87	5.50	0.16	1.23	2.77	5.50	9.26

Table 4: **Risk Exposure to the Bond Market.** This table shows the bond market risk exposure (β) of mutual funds. Funds are categorised as Amplifying or Hedging if their derivative use amplifies or hedges their other portfolio returns, specifically the correlation of their derivative returns with their non-derivative returns is in the top or bottom tercile, or None if they never hold derivatives. Also shown is their bond market α. t-stats are in parentheses.

	Amplify	None	Hedge
Market β	0.896	0.783	0.566
	(17.92)	(37.35)	(10.38)
Market α	-0.055	0.021	0.109
	(-1.09)	(1.04)	(2.01)
R^2	0.1617	0.2023	0.0658
Observations	1666	5501	1533

Table 5: **Fund Returns, Flows, and Characteristics by Derivative Use.** This table shows the mean, median, and standard deviation of monthly mutual fund returns, investor fund flows, expense ratios, and total net assets between July 2019 and June 2020. Funds are categorised as Amplifying or Hedging if their derivative use amplifies or hedges their other portfolio returns, specifically the correlation of their derivative returns with their non-derivative returns is in the top or bottom tercile, or None if they never hold derivatives. Fund returns, fund flows, and expense ratio are in percent. Total net assets are in millions of dollars.

	Mean			Median			Std. Dev.		
	Amplify	None	Hedge	Amplify	None	Hedge	Amplify	None	Hedge
Fund Returns	0.403	0.439	0.105	0.522	0.463	0.486	2.93	2.442	3.612
Fund Flows	1.174	0.542	-0.657	0.449	-0.051	-0.399	6.471	5.34	4.123
Expense Ratio	0.59	0.643	0.739	0.574	0.607	0.72	0.292	0.278	0.258
Total Net Assets	5332	1448	3164	1020	278	389	9503	4593	9263

Table 6: **Holdings by Derivative Use - Quarterly.** This table shows mutual fund holdings, averaged quarterly within one of three fund groups: funds are categorised as Amplifying or Hedging if their derivative use amplifies or hedges their other portfolio returns, or None if they never hold derivatives. Cash-derivatives denotes cash specifically offset for funds' derivative holdings. Government denotes government bonds. Corporate denotes corporate bonds. Municipal denotes municipal bonds. Securitized denotes asset-backed and mortgage-backed securities.

	Mean			Median			Std. Dev.		
	Amplify	None.	Hedge	Amplify	None	Hedge	Amplify	None	Hedge
Cash	0.2	1.5	-2.8	0	0	0	8.6	5.7	18.2
Cash-Derivatives	-0.7	0.2	-1.7	0	0	0	4.5	1.5	28.9
Government	26.4	22.3	28.8	25.3	7.4	10.6	24.5	24.9	33.1
Corporate	55.6	51.7	57.1	45.8	45.4	61.8	29.9	35.4	35
Derivatives	1.6	0	3.7	0	0	0	4.6	0	30.1
Municipal	1.1	1.4	1.7	0.2	0	0	2.4	4.4	10
Securitized	11.1	5.9	7.5	7.7	0	2.1	13.1	10.3	10.4
Others	5.5	8.8	4.4	1.4	1.9	1.5	14.6	23.3	11.9

Table 7: **Trading of Corporate Bonds in Response to Flows and Cash Holdings.** This table shows the results of a regression of mutual funds' corporate bond trading on several factors. Flows is the fund's net inflows. Cash is the fund's cash. Illiquidity is half the difference between the mean prices at which customers buy from, and sell to, dealers. Duration is the bond's duration, as a measure of interest rate risk. Excess returns are lagged one period. Standard errors are clustered at the monthly level. t-stats are in parentheses.

	Outflows Sample	Inflows Sample
Flows	0.527	0.468
	(8.98)	(4.80)
Flows*Cash	-0.013	-0.006
	(-4.01)	(-1.48)
Cash	0.013	0.041
	(0.83)	(2.35)
Flows*Illiquidity	-0.015	-0.098
	(-0.21)	(-1.85)
Illiquidity	0.153	-0.045
	(0.78)	(-0.25)
Flows*1{Investment Grade}	-0.098	0.046
	(-1.75)	(0.44)
1{Investment Grade}	-0.738	-1.05
	(-5.95)	(-4.97)
Flows*Duration	0.000	0.008
	(0.02)	(0.65)
Duration	-0.008	0.019
	(-0.58)	(0.78)
Flows*Excess returns	-0.007	0.002
	(-1.41)	(0.51)
Excess returns	-0.019	0.019
	(-1.11)	(1.11)
Year-Month Fixed Effects	Yes	Yes
R^2	0.0147	0.0365
Observations	1051458	930088

Table 8: **Trading of Corporate Bonds by Derivative Use.** This table shows the results of a regression of mutual funds' corporate bond trading on several factors. Funds are categorised as Amplifying or Hedging if the correlation of their derivative returns with their non-derivative returns is in the top or bottom tercile, or None if they never hold derivatives. Flows is the fund's net inflows. Cash is the fund's cash. Illiquidity is half the difference between the mean prices at which customers buy from, and sell to, dealers. Duration is the bond's duration, as a measure of interest rate risk. Excess returns are lagged one period. Standard errors are clustered at the monthly level. t-stats are in parentheses.

	Outflows Sample		
	Amplify	None	Hedge
Flows	0.482	0.545	0.279
	(2.35)	(5.20)	(2.57)
Flows*Cash	-0.018	-0.01	0.007
	(-6.80)	(-1.58)	(0.77)
Cash	-0.051	0.06	-0.011
	(-1.13)	(1.57)	(-0.36)
Flows*Illiquidity	-0.141	-0.074	-0.184
	(-1.16)	(-1.38)	(-2.3)
Illiquidity	-0.546	-0.166	0.293
	(-1.50)	(-0.98)	(0.79)
Flows*1{Investment Grade}	-0.323	-0.091	0.043
	(-2.34)	(-1.25)	(0.46)
1{Investment Grade}	-1.101	-0.648	-0.984
	(-3.76)	(-3.95)	(-2.67)
Flows*Duration	0.029	-0.003	-0.007
	(2.48)	(-0.53)	(-0.94)
Duration	0.063	0.012	-0.057
	(1.98)	(0.66)	(-3.26)
Flows*Excess returns	0.007	-0.016	0.007
	(0.81)	(-2.36)	(0.72)
Excess returns	-0.042	-0.033	0.032
	(-1.23)	(-1.31)	(1.06)
Year-Month Fixed Effects	Yes	Yes	Yes
R^2	0.019	0.020	0.017
Observations	67945	415404	120015

Table 9: **Trading of Government Bonds in Response to Flows and Cash Holdings.** This table shows the results of a regression of mutual funds' government bond trading on a number of factors. Flows is the fund's net inflows. Cash is the fund's cash. Illiquidity is half the difference between the mean prices at which customers buy from, and sell to, dealers. Duration is the bond's duration, as a measure of interest rate risk. Returns are lagged one period. Standard errors are clustered at the monthly level. t-stats are in parentheses.

	Outflows Sample	Inflows Sample
Flows	0.65258	0.62014
	(3.81)	(3.26)
Flows*Cash	-0.0067	-0.00323
	(-0.56)	(-0.46)
Cash	0.0216	-0.00152
	(0.69)	(-0.04)
Flows*Illiquidity	-0.00414	1.49914
	(0.00)	(0.47)
Illiquidity	-7.18254	-11.9602
	(-0.75)	(-1.05)
Flows*Duration	-0.00003	0.00000
	(-1.24)	(0.12)
Duration	0.00025	0.0004
	(2.94)	(3.93)
Flows*Returns	0.02439	0.01769
	(1.28)	(0.96)
Returns	0.22396	-0.08758
	(2.50)	(-0.94)
Year-Month Fixed Effects	Yes	Yes
R^2	0.011	0.026
Observations	70553	60960

Table 10: **Trading Sensitivities by Magnitude of Outflows Relative to Cash Holdings - Outflows Sample.** This table shows the results of a regression of mutual funds' corporate bond and cash trading on the interaction of investor outflows and funds' cash reserves, grouped into outflows being less than 50%, 50-100%, 100-150%, and more than 150% of cash reserves. Standard errors are clustered at the monthly level. t-stats are in parentheses.

	Sensitivity of cash trading	Sensitivity of bond trading
Flows*1{|Outflows| < 0.5Cash}	2.697	0.181
	(17.82)	(1.79)
Flows*1{0.5Cash≤ |Outflows| <Cash}	0.734	0.239
	(10.6)	(4.61)
Flows*1{Cash≤ |Outflows| <1.5Cash}	0.412	0.251
	(7.91)	(5.57)
Flows*1{1.5Cash≤ |Outflows|}	-0.008	0.492
	(-0.31)	(8.84)
Year-Month Fixed Effects	Yes	Yes
Controls	No	Yes
R^2	0.560	0.015
Observations	11007	1051458

Table 11: **Liquidity Costs of Corporate Bonds.** This table shows the results of a regression of the liquidity costs of corporate bonds on several factors. Aggregate Mean Trade is the percentage increase in funds' bond holding (in number of shares) averaged across all funds. Aggregate Mean Cash Shortfall is the mean difference between investor flows and their cash reserves, i.e. cash minus outflows, averaged across all funds. Outstanding denotes the amount of the bond issue still outstanding in US dollars. $Volume denotes the total monthly trading volume in millions of dollars. Fund Flows denote investor fund flows in percent. Duration is the bond's duration, as a measure of interest rate risk. 1{IG} is an indicator variable, equal to 1 if the bond's credit rating is investment grade, and 0 if it's high yield. Standard errors are clustered at the monthly level. t-stats are in parentheses.

	All Sample	GFC Sample	Covid-19 Sample
Aggregate Mean Trade	-0.0002	-0.0039	-0.0018
	(-3.29)	(-2.71)	(-2.02)
Aggregate Mean Cash Shortfall	0.0000	0.0013	0.0032
	(0.01)	(0.81)	(3.19)
Log(Outstanding)	-0.0232	0.1649	-0.0957
	(-6.97)	(7.26)	(-5.33)
Log($volume) lagged	0.0021	-0.0084	0.0273
	(3.07)	(-0.87)	(3.42)
Log($volume)	-0.0199	-0.0154	0.0048
	(-16.95)	(-1.56)	(0.52)
Duration lagged	0.0164	0.0287	0.0253
	(41.52)	(6.37)	(17.27)
1{Investment Grade}	-0.0635	0.1691	-0.1904
	(-15.97)	(6.40)	(-7.16)
Year-Month Fixed Effects	Yes	No	No
R^2	0.589	0.597	0.639
Observations	705638	2259	4629

Table 12: **Changes in Liquidity Costs of Corporate Bonds.** This table shows the results of a regression of changes in the liquidity costs of corporate bonds on several factors. Aggregate Mean Trade is the percentage increase in funds' bond holding (in number of shares) averaged across all funds. Aggregate Mean Cash Shortfall is the mean difference between investor flows and their cash reserves, i.e. cash minus outflows, averaged across all funds. Outstanding denotes the amount of the bond issue still outstanding in US dollars. $Volume denotes the total monthly trading volume in millions of dollars. Fund Flows denote investor fund flows in percent. Duration is the bond's duration, as a measure of interest rate risk. 1{IG} is an indicator variable, equal to 1 if the bond's credit rating is investment grade, and 0 if it's high yield. Standard errors are clustered at the monthly level. t-stats are in parentheses.

	All Sample	GFC Sample	Covid-19 Sample
Aggregate Mean Trade	-0.0001	-0.0027	-0.0019
	(-2.93)	(-1.45)	(-2.36)
Aggregate Mean Cash Shortfall	-0.0001	0.0007	0.0025
	(-0.94)	(0.45)	(2.52)
Log(Outstanding)	0.0000	0.0943	-0.0634
	(0.04)	(4.25)	(-3.60)
Log($volume) lagged	0.0193	0.0214	0.0203
	(23.26)	(1.86)	(2.57)
Log($volume)	-0.0189	-0.0058	0.0175
	(-20.7)	(-0.50)	(1.94)
Duration lagged	0.0003	0.0038	0.0155
	(1.26)	(0.80)	(10.49)
1{Investment Grade}	-0.0009	0.172	-0.0732
	(-0.46)	(6.53)	(-3.01)
Year-Month Fixed Effects	Yes	No	No
R^2	0.050	0.520	0.532
Observations	671708	2043	4488

Table 13: **Corporate Bond Returns.** This table shows the results of a regression of corporate bond returns on several factors. Aggregate Mean Trade is the percentage increase in funds' bond holding (in number of shares) averaged across all funds. Aggregate Mean Cash Shortfall is the mean difference between investor flows and their cash reserves, i.e. cash minus outflows, averaged across all funds. Outstanding denotes the amount of the bond issue still outstanding in US dollars. $Volume denotes the total monthly trading volume in millions of dollars. Fund Flows denote investor fund flows in percent. Duration is the bond's duration, as a measure of interest rate risk. 1{IG} is an indicator variable, equal to 1 if the bond's credit rating is investment grade, and 0 if it's high yield. Standard errors are clustered at the monthly level. t-stats are in parentheses.

	All Sample	GFC Sample	Covid-19 Sample
Aggregate Mean Trade	0.0073	0.0221	0.0424
	(5.43)	(0.98)	(1.79)
Aggregate Mean Cash Shortfall	-0.0051	-0.0321	-0.0782
	(-1.42)	(-1.75)	(-4.29)
Log(Outstanding)	-0.054	-1.8525	2.8868
	(-1.55)	(-5.63)	(7.81)
Log($volume) lagged	-0.0652	0.327	-0.9006
	(-4.31)	(3.13)	(-6.66)
Log($volume)	0.0797	-0.7461	0.5238
	(5.33)	(-6.33)	(3.00)
Duration lagged	0.031	-0.2993	-0.3997
	(2.15)	(-6.62)	(-16.86)
1{Investment Grade}	-0.1713	1.3126	12.1466
	(-1.20)	(3.26)	(15.95)
Year-Month Fixed Effects	Yes	No	No
R^2	0.191	0.405	0.504
Observations	757705	2616	4756

6 Appendix

Some extra detail is provided for the proofs in the theoretical model.

6.1 Proofs

We can re-write the fund's utility function by conditioning on its investor flows at time $t+1$:

$$
\begin{aligned}
E_t\left[cash_{t+1} + bonds_{t+1}v_{t+1}\right] &= E_t\left[E_t\left[cash_{t+1} + bonds_{t+1}v_{t+1} \mid f_{t+1}\right]\right] \\
&= \int_{cash_t}^{\bar{f}} g(f)E_t\left[\left(bonds_{t-1} + q_t - \frac{f - cash_t}{p_{t+1}}\right)v_{t+1}\right]df \\
&\quad + \int_{\underline{f}}^{cash_t} g(f)E_t\left[cash_t - f + \left(bonds_{t-1} + q_t\right)v_{t+1}\right]df \\
&= \int_{\underline{f}}^{cash_t} g(f)E_t\left[cash_t - f\right]df \\
&\quad + \left(bonds_{t-1} + q_t\right)E_t[v_{t+1}]\int_{\underline{f}}^{\bar{f}} g(f)df \\
&\quad - \int_{cash_t}^{\bar{f}} g(f)E_t\left[\left(\frac{f - cash_t}{p_{t+1}}\right)v_{t+1}\right]df \\
&= \int_{\underline{f}}^{cash_t} g(f)E_t\left[cash_t - f\right]df + \int_{cash_t}^{\bar{f}} g(f)E_t\left[cash_t - f\right]df \\
&\quad + \left(bonds_{t-1} + q_t\right)E_t[v_{t+1}] \\
&\quad - \int_{cash_t}^{\bar{f}} g(f)E_t\left[\left(\frac{cash_t - f}{p_{t+1}}\right)p_{t+1}\right]df - \int_{cash_t}^{\bar{f}} g(f)E_t\left[\left(\frac{f - cash_t}{p_{t+1}}\right)v_{t+1}\right]df \\
&= \int_{\underline{f}}^{\bar{f}} g(f)E_t\left[cash_t - f\right]df + \left(bonds_{t-1} + q_t\right)E_t[v_{t+1}] \\
&\quad - \int_{cash_t}^{\bar{f}} g(f)E_t\left[\left(\frac{cash_t - f}{p_{t+1}}\right)\left(p_{t+1} - v_{t+1}\right)\right]df
\end{aligned}
$$

The utility function becomes:

$$
\begin{aligned}
E_t\left[cash_{t+1} + bonds_{t+1}v_{t+1}\right] - \lambda_t(p_t bonds_t)^2 \;=\; & \underbrace{cash_t - E_t[f_{t+1}] + (bonds_{t-1} + q_t)\,E_t[v_{t+1}]}_{\text{AUM if no cash shortfall}} \\
& - \underbrace{E_t\left[(p_{t+1} - v_{t+1})\,q^{-}_{t+1} \mid cash_t < f_{t+1}\right]}_{\text{AUM deduction if shortfall}} \\
& - \underbrace{\lambda_t(p_t(bonds_{t-1} + q_t))^2}_{\text{penalty for risk}}
\end{aligned}
$$

Substituting in $cash_t = cash_{t-1} - f_t - p_t q_t$:

$$
\begin{aligned}
& \int_{cash_t}^{\bar{f}} g(f) E_t\left[\left(\frac{cash_t - f}{p_{t+1}}\right)(p_{t+1} - v_{t+1})\right] df \\
= & \frac{1}{\bar{f} - \underline{f}} \int_{cash_{t-1} - f_t - p_t q_t}^{\bar{f}} E_t\left[\left(\frac{cash_{t-1} - f_t - p_t q_t - f}{p_{t+1}}\right)(p_{t+1} - v_{t+1})\right] df \\
= & \frac{1}{\bar{f} - \underline{f}} E_t\left[\left(\frac{(cash_{t-1} - f_t - p_t q_t) f - f^2/2}{p_{t+1}}\right)(p_{t+1} - v_{t+1})\right]_{cash_{t-1} - f_t - p_t q_t}^{\bar{f}} \\
= & \frac{1}{\bar{f} - \underline{f}} E_t\left[\left(\frac{(cash_{t-1} - f_t - p_t q_t)\bar{f} - \bar{f}^2/2}{p_{t+1}}\right)(p_{t+1} - v_{t+1})\right] \\
& - \frac{1}{\bar{f} - \underline{f}} E_t\left[\left(\frac{(cash_{t-1} - f_t - p_t q_t)^2/2}{p_{t+1}}\right)(p_{t+1} - v_{t+1})\right]
\end{aligned}
$$

Using $p_{t+1} - v_{t+1} = c_{t+1} Q_{t+1}$, the first order condition with respect to q_t is:

$$
\begin{aligned}
0 \;=\; & E_t[v_{t+1}] - p_t - 2\lambda_t p_t^2 (bonds_{t-1} + q_t) \\
& - \frac{p_t}{\bar{f} - \underline{f}} E_t\left[\left(cash_{t-1} - f_t - p_t q_t - \bar{f}\right)\left(\frac{c_{t+1} Q_{t+1}}{p_{t+1}}\right)\right]
\end{aligned}
$$

Rearranging:

$$
p_t q_t = \frac{\overbrace{E_t[v_{t+1}/p_t] - 1}^{\text{expected return}} - \overbrace{2\lambda_t p_t bonds_{t-1}}^{\text{extra risk}} - \overbrace{\frac{1}{\bar{f} - \underline{f}}\left(cash_{t-1} - f_t - \bar{f}\right)}^{\text{expected \$ shortfall at time } t+1} \overbrace{E_t\left[\frac{c_{t+1} Q_{t+1}}{p_{t+1}}\right]}^{\text{\% illiquidity}}}{2\lambda_t p_t - \frac{1}{\bar{f} - \underline{f}} E_t\left[\frac{c_{t+1} Q_{t+1}}{p_{t+1}}\right]}
$$

Table A1: **Holdings by Derivative Use - Monthly.** This table shows mutual fund holdings, averaged monthly within one of three fund groups: funds are categorised as Amplifying or Hedging if their derivative use amplifies or hedges their other portfolio returns, or None if they never hold derivatives. Cash-derivatives denotes cash specifically offset for funds' derivative holdings. Government denotes government bonds. Corporate denotes corporate bonds. Municipal denotes municipal bonds. Securitized denotes asset-backed and mortgage-backed securities.

	Mean			Median			Std. Dev.		
	Amplify	None	Hedge	Amplify	None	Hedge	Amplify	None	Hedge
Cash	1.2	1.1	0.4	0	0	0.2	4.8	3.5	9.6
Cash-Derivatives	0	0.2	0.5	0	0	0	2.9	1.1	16.2
Government	26.8	24.6	19.2	27.6	17.6	2.1	22.2	25.2	31
Corporate	51.6	50.7	64.3	43.5	43.9	85.9	27.9	34	34.5
Derivatives	1	0	-0.1	0	0	0	3.6	0	18.2
Municipal	1	1.2	2.9	0.1	0	0	1.9	3.6	13.7
Securitized	12	7.1	7.4	13	0.8	1.1	10.3	11.2	11.4
Others	6.7	6.8	4.3	0.7	1.6	1	17.9	18.7	12