LASH risk and Interest Rates[☆]

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March 2, 2026

Abstract

We study a form of liquidity risk we call Liquidity After Solvency Hedging ("LASH") risk. Institutions take LASH risk when hedging solvency risk with strategies that require liquidity as solvency improves. Using UK regulatory data covering the near-universe of interest rate hedges, we measure interest rate-driven LASH risk in the non-bank sector. Institutions with longer-duration liabilities take greater LASH risk when rates fall. At its peak, a 100bps rise in yields implied liquidity needs close to the aggregate cash holdings of UK pension funds and insurers. During the 2022 LDI crisis, pre-crisis LASH risk predicts bond sales and yield spikes.

Keywords: Liquidity, Monetary policy, Financial crisis, Hedging
JEL Codes: E44, F30, G10, G22, G23

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1 Introduction

Liquidity crises have become increasingly common in the non-bank financial sector. Recent examples include the pandemic-era liquidity crisis of Spring 2020, the 2022 commodity market turmoil following Russia's invasion of Ukraine, and the 2022 UK bond market crisis. These liquidity crises are linked to the rising use of hedging instruments—such as swaps and repos—by pension funds, insurers, and alternative investment funds. This paper relates these crises to an understudied form of liquidity risk related to hedging. We label this risk *Liquidity After Solvency Hedging* or "LASH" risk. Institutions take LASH risk when they hedge against losses, using strategies that lead to liquidity needs when the institution's solvency improves. As such, LASH is distinct from other forms of liquidity risk, which typically materialize when solvency deteriorates.[1]

As a preamble to the empirical contributions of the paper, we develop a simple framework to define LASH risk and differentiate it from other forms of liquidity risk. As an example, consider a fund, such as a life insurer or pension fund, with long-duration liabilities and shorter-duration assets. A fall in interest rates lowers solvency since the value of liabilities rises more than the value of assets. The fund can hedge this solvency risk using an interest rate swap, whose value rises when rates fall. This hedging strategy creates liquidity needs when rates rise. As rates rise, the value of the swap falls, and the fund must pay liquid assets ("margin") to its counterparty equal to the fall in the swap's value. The margin requirement represents LASH risk, which materializes even if the solvency of the fund improves with rising rates.

We formalize LASH risk using a simple model of portfolio choice. There is a fund endowed with long-duration liabilities, which faces duration risk from shocks to interest rates. The model has four empirically grounded ingredients. First, the fund faces costs from insolvency–defined as negative net worth–and these costs generate risk aversion and a desire for hedging. One interpretation of these costs is regulatory penalties from insolvency, but costs other than regulation may also matter. Second, the fund can hedge duration risk only through interest rate derivatives, which require margin and thus generate liquidity risk. The derivative is best interpreted as a swap, but we discuss how LASH risk applies to other hedging instruments such as repo. The fund does not have access to assets of long enough duration to hedge the liability. The third ingredient is that holding liquid assets is costly, as they command a premium; this prevents the fund from self-insuring liquidity risk. Fourth, the fund can hold

[1] For work on the disruption in bond markets during the pandemic-era liquidity crisis, see Haddad, Moreira and Muir (2021). For the commodity market turmoil see Avalos and Huang (2022). For the UK bond market crisis in 2022, see Breeden (2022).

medium-duration assets, which have a higher return than liquid assets but incur a liquidity cost when sold. With these four ingredients, the fund optimally chooses its hedging strategy.

The model generates three predictions that guide our empirical contributions. First, the optimal strategy partially hedges solvency risk from falling rates, i.e. risks to net worth, at the cost of some liquidity risk from rising rates, i.e. the risk of margin calls. The fund's solvency improves after a shock that increases rates. Yet despite this improvement in net worth, the fund may need to liquidate assets to pay variation margin on the swap. This liquidity–solvency trade-off motivates only partial hedging. Second, incentives to take LASH risk are higher in a low interest rate environment. Since the fund is only partially hedged against interest rate risk, net worth is low when rates are low, meaning the fund is closer to insolvency. Since insolvency is costly and nearer, the fund has a greater incentive to hedge against interest rate risk–at the cost of more LASH risk. Third, a large enough positive shock to rates can lead to a "liquidity crisis": funds exhaust their holdings of short-term and liquid assets, requiring costly sales of medium-term assets to pay margin, even as solvency improves.

The simple framework clarifies that LASH risk is different from some other common forms of liquidity risk. LASH risk relates neither to maturity transformation and callable claims (Diamond and Dybvig, 1983; Farhi and Tirole, 2012), nor to rollover risk (Calvo, 1988; Cole and Kehoe, 2000; Aguiar, Chatterjee, Cole and Stangebye, 2022). Moreover, in our example, the fund is exposed to LASH risk precisely when its solvency improves due to rising rates. Therefore, LASH risk differs from the feedback between funding and market liquidity (Brunnermeier and Pedersen, 2009), which arises when solvency deteriorates. In the example, LASH risk applies to institutions with long-duration liabilities and short-duration assets, the opposite maturity structure of a typical bank. While our example and empirical analysis focus on interest rates, we also discuss and present case studies illustrating how the same principles apply to other asset prices, such as commodities and exchange rates.

We then make three empirical contributions that match the predictions of the model. In our first empirical contribution, we show that non-banks take on LASH risk to partially hedge solvency risk. We measure LASH risk for pound sterling interest rate contracts held by UK non-banks. In this context, LASH risk measures the liquid assets an institution must pay as a margin for a given change in interest rates. For instance, suppose an investment fund holds an interest rate swap to hedge against falling rates. We measure the liquid assets the fund must pay to its counterparty when the value of the swap falls because rates have risen. We apply the measure to regulatory data from the Bank of England on the near-universe of sterling repo transactions, pound sterling interest rate swap positions and UK government bond transactions. Our measure is available at the institution level and in real time, starting from 2019. LASH risk from interest rates concentrates in the pension fund and life insurance sector—i.e. financial institutions with long-duration liabilities. We find that LASH risk is large: at the peak level of risk, a 100bps rise in interest rates would have generated liquidity needs close to the liquid asset holdings of the entire UK pension fund and insurance sector. During some crisis episodes, such as the 2022 UK bond market crisis that we will discuss shortly, rates have risen significantly more than 100bps in a short time window. We also show that pension funds are partially, but not fully hedged against interest rate changes—their solvency improves when interest rates rise.

Our second empirical contribution is to show that low interest rates cause LASH risk. In the time series, LASH risk is high when interest rates are low: it rises from 2019 through 2022 as yields fall, and then declines as yields rise. While this pattern is consistent with low rates increasing LASH risk, there are plausible confounders—for instance, macroeconomic shocks could affect both interest rates and incentives to hedge. We therefore pursue a cross-sectional identification strategy. We identify institutions whose solvency is more sensitive to rate movements using predetermined proxies for the duration exposure of their balance sheets. We find that when rates fall, these exposed institutions take on more LASH risk than others, exactly as our framework predicts. This finding is robust across specifications, including a demanding design that exploits cross-sectional variation in bond-level convexity within institutions' initial bond holdings and allows institution-specific sensitivities to yield levels, thereby controlling for all time-invariant determinants of how hedging responds to interest rate changes.

Our third empirical contribution is to show that when rates rise sharply, the LASH risk caused by the previous decline in rates leads to liquidity crises. LASH risk is not itself the "root cause" of crises, but instead amplifies a sudden, initial rise in rates. Due to margin calls, pension funds must sell bonds to raise liquid assets, which leads rates to rise even more. We study the liquidity crisis in the UK pension fund sector in September and October 2022. That period was characterized by sharply rising interest rates, margin calls, and gilt sales by UK pension funds. We find that institutions with ex-ante larger LASH risk sold substantially higher quantities of gilts during the crisis: a one standard deviation increase in pre-crisis LASH risk is associated with more than 15% higher daily sell volumes during the crisis. Gilt sales due to LASH risk exacerbated the crisis further. High LASH risk institutions significantly contributed to the yield spike in the gilt market: a one standard deviation increase in gilt sales due to LASH risk leads to a 4.1bps daily increase in gilt yields (or 66bps over the entire 16-day crisis period).

Consistent with our framework, the solvency of the pension fund sector *improved* during the liquidity crisis. Could pension funds have used their improving solvency to raise liquid assets and avert the crisis? Liquidity needs from LASH risk are hard to fulfill for three reasons. First, the improvement in solvency comes from a fall in the value of liabilities, which cannot be pledged as collateral. Second, liquidity supply in secured credit markets is often constrained during crises (see, e.g., Afonso, Cipriani, Copeland, Kovner, Spada and Martin, 2021; Duffie, 2022). During the 2022 crisis, repo rates spiked, suggesting supply constraints. Funds that borrowed from ex ante supply-constrained repo lenders sold particularly many bonds during the crisis. Third, institutions differed in their ability to mobilize liquidity quickly. For instance, only about half of the institutions that were active in the swap market also participated in the repo market; we show that accessing liquidity for these funds was particularly challenging. Moreover, many institutions hedged their liquidity risk by pooling together with other funds into specialized entities. We show that the pooled structure slowed the transfer of liquidity to where it was scarce.

Our evidence about LASH risk is for the UK non-bank sector. But is LASH risk important more generally? As we discuss in Section 2, there are many examples of LASH risk, suggesting that the lessons of this paper apply beyond the UK. Often these examples are narrative accounts; our paper provides more systematic evidence. One classic example of LASH risk is the 1993 failure of energy conglomerate Metallgesellschaft, which offered customers price guarantees for heating. These guarantees would lead to solvency risk if energy prices rose, which Metallgesellschaft hedged. When the energy price fell, the company's solvency improved, but it faced margin calls that led to its failure (Culp and Miller, 1994).[2]

Given that LASH risk is different from other forms of liquidity risk, there are also different policy implications. Typically, policymakers worry about providing liquidity support during crises. For instance, Bagehot's Dictum states that policymakers should provide liquidity support only at a penalty rate. The reason is that institutions often require liquidity support when their solvency deteriorates, and providing support ex post encourages solvency risk and moral hazard ex ante (Farhi and Tirole, 2012). LASH risk is different. Institutions increase LASH risk when they hedge against solvency risk. Therefore, mitigating the adverse effects of LASH risk ex post—for instance, by providing liquidity support during crises—may *reduce* solvency risk by encouraging hedging ex ante, though it can also affect incentives to use liquidity-intensive hedging strategies. Policymakers are actively debating these questions

[2]More recently, Czech et al. (2023) show that non-US non-banks that held dollar assets financed with domestic currency liabilities were forced to liquidate assets at the onset of the Covid pandemic in spring 2020. These sales were triggered by margin calls on foreign exchange hedging positions, even though the appreciation of the US dollar raised the value of their dollar-denominated asset holdings.

(e.g., Hauser, 2023a).

Related literature. This paper relates to three literatures. First, we contribute to the literature on liquidity risk, which has traditionally centered on banks and illiquidity stemming from maturity transformation or coordination failures (Diamond and Dybvig, 1983; Diamond and Rajan, 2001; Rochet and Vives, 2004; Morris and Shin, 2004; Farhi and Tirole, 2012; Cooperman, Duffie, Luck, Wang and Yang, Forthcoming). Closest to our work within this literature, Drechsler, Savov, Schnabl and Wang (2023) study how interest rates affect the trade-off between liquidity and solvency in the context of the banking system. In their model, low rates reduce solvency by reducing the value of banks' deposit franchises. High rates create liquidity risk because the deposit franchise becomes a runnable asset.[3] Our setting shares the feature that interest rates affect the trade-off between liquidity and solvency. However, with LASH risk, the source of liquidity risk does not relate to the deposit franchise or to banks specifically. Instead, LASH risk applies to non-banks or, more generally, any institution that hedges solvency risks with strategies that generate liquidity needs when solvency improves.

Within the broader literature on liquidity risk, Brunnermeier (2009), Adrian, Kiff and Shin (2018), and Bernanke (2018) document mechanisms, causes, and effects of the liquidity crises during the Great Financial Crisis. Borio, Claessens, Schrimpf and Tarashev (2023) link liquidity crises to collateral use. Recent papers analyze the "Dash for Cash" liquidity crisis during the onset of the Covid-19 pandemic (Haddad, Moreira and Muir, 2021), including the role of mutual funds' and life insurers' liquidity transformation (Ma, Xiao and Zeng, 2022; Huang, Jiang, Liu and Liu, 2021; Foley-Fisher, Heinrich and Verani, 2023), and the role of holding dollar assets for foreign investors (Czech, Huang, Lou and Wang, 2023; Cesa-Bianchi, Czech and Eguren-Martin, 2023). Pinter (2023) and Chen and Kemp (2023) dissect the market dynamics and policy response during the UK bond market crisis in autumn 2022. Pinter, Siriwardane and Walker (2024) provide a forensic account of how fire sales of safe assets, abetted by slow-moving capital, were a key feature of the UK crisis. Our paper shows that solvency hedging is an important contributor to certain liquidity crises, which implies distinct policy implications.

Some research focuses on how deteriorating solvency raises liquidity risk via margin calls (e.g., Brunnermeier and Pedersen, 2009). LASH risk also operates via margin calls. However, LASH risk happens when solvency improves. As such, LASH risk is an instance of what is known to practitioners as "right-way risk": when a counterparty's solvency improves as

[3] The extent to which banks bear interest rate risk from their deposit franchises (Krishnamurthy et al., 2024), securities holdings (Jiang et al., 2023) or derivative positions (McPhail et al., 2023) is still a topic of debate in the literature. For the non-banks exposed to LASH risk, we find that even after accounting for hedging, rates and solvency have a clear negative association.

its payment obligations increase (Canabarro and Duffie, 2003). The liquidity risk arising from falling solvency, as in Brunnermeier and Pedersen (2009), is an instance of "wrong-way risk". In principle, these comovements with solvency should alter the optimal margining embedded in the hedging contract. The theoretical literature has studied optimal margining in the presence of counterparty risk and moral hazard (e.g., Biais et al., 2020). We take the presence and degree of variation margining as a primitive, motivated by regulations that require the full margining of derivatives positions to eliminate counterparty risk.

A second literature to which our paper contributes studies interest rates and financial stability. Various papers document how lower interest rates raise risk-taking (e.g., Adrian and Shin, 2010; Jiménez, Ongena, Peydró and Saurina, 2014) and lead to credit creation and subsequent financial instability (e.g., Grimm, Jordà, Schularick and Taylor, 2023). Other papers document the relationship between interest rates and risk-taking through 'reach for yield' behavior, in the context of insurers, pension funds, mutual funds, and banks (Becker and Ivashina, 2015; Domanski, Shin and Sushko, 2017; Martinez-Miera and Repullo, 2017; Lu, Pritsker, Zlate, Anadu and Bohn, 2023; Aramonte, Lee and Stebunovs, 2022) and the interaction with FX risk (Bertaut, Bruno and Shin, 2023).[4] We contribute to this literature by studying a specific mechanism: how low interest rates raise *liquidity* risk by increasing incentives to hedge solvency risk with derivatives.

Third, we contribute to the literature studying pension funds and related non-bank institutions (see Scharfstein (2018) for an overview).[5] A closely related paper is Klingler and Sundaresan (2019), who show that under-funded pension funds have a higher demand for hedging via swaps. We build upon their work by providing evidence of a link between interest rates and the demand for hedging that operates through a general relationship with solvency. Beyond their paper, we connect pension fund hedging to liquidity risk, which has various additional implications. A second related paper is Jansen, Klingler, Ranaldo and Duijm (2023), who study hedging with swaps in the Dutch pension fund sector. They explore how regulation leads pension funds to use swaps, creating liquidity risk when interest rates rise. We complement the paper in various ways. Our paper points out that falling interest rates are another cause of liquidity risk from hedging instruments. We also connect pension

[4] Adrian and Liang (2018) and Boyarchenko, Favara and Schularick (2022) provide comprehensive reviews.

[5] Lucas and Zeldes (2009) investigate how reforms to the discount rates applied to pension funds' liabilities affect the asset allocation of pension funds. Greenwood and Vayanos (2010), Greenwood and Vissing-Jorgensen (2018) and Jansen (2021) provide sharp evidence that pension funds' behavior affects interest rates and spills over to other sectors. Koijen and Yogo (2022) investigate how risk-based capital regulation affects the portfolio choice of life insurers. Foley-Fisher, Narajabad and Verani (2020) document self-fulfilling runs within the life insurance industry. Sen (2023) analyses how regulation and interest rates shape US life insurers' hedging behavior, while Foley-Fisher, Heinrich and Verani (2023) document their cash management behavior in times of stress.

funds' hedging strategies to a salient liquidity crisis, the 2022 UK bond market crisis. Most broadly, we emphasize how improving solvency accompanies the liquidity risk from these hedging strategies—which is crucial for regulation.

Outline. The paper is organized as follows. Section 2 provides motivating evidence and develops a simple framework that will guide our empirical analysis, which predicts that (i) funds partially hedge solvency risk by taking on LASH risk, (ii) incentives to take on LASH risk are greater in a low rate environment, and (iii) a large enough positive shock to rates generates a liquidity crisis. Section 3 presents the context, data, and strategy to measure LASH risk. Section 4 shows that pension funds partially hedge solvency risk at the cost of taking on LASH risk. Section 5 shows that low rates cause higher LASH risk. Section 6 shows how LASH risk contributed to the UK bond market crisis in 2022. Section 7 concludes.

2 LASH Risk: Motivation and a Simple Framework

This section provides motivating evidence that LASH risk is pervasive across time periods and asset classes. It then develops a simple model focused on interest rate risk to fix ideas and guide the empirical analysis. The model delivers three predictions that structure the empirics: (i) funds partially hedge solvency risk by taking on LASH risk, (ii) incentives to take on LASH risk are greater in a low rate environment, and (iii) a large enough increase in rates can generate a liquidity crisis even as solvency improves.

LASH risk arises in a wide range of settings, so the lessons of this paper—while grounded in UK non-banks—may apply more broadly. Table 1 summarizes episodes in which LASH risk contributed to financial distress, spanning 1993 to the present and covering asset classes that include commodities (including energy), FX hedges, and interest rate derivatives. There is a common theme across the episodes: institutions seek to hedge solvency risk. Suddenly, the asset price moves in their favor, improving solvency. But at the same time, the value of the hedge falls. The institution faces margin calls and financial distress due to poor liquidity, even as its solvency improves. Appendix A discusses each episode in detail. Many of these episodes are discussed by academic work that is narrative, and takes the form of a case study. We instead provide detailed measurement of the scale of LASH risk using microdata; as well as evidence on the causes and consequences of LASH risk. The rest of this section introduces a framework that focuses on interest rates specifically, to match our empirical setting.

Table 1 Summary of LASH Risk Episodes

Episode	Background	Trigger Event	Reason for Improved Solvency	Consequences	References
Metallgesellschaft (1993)	Metallgesellschaft was a German energy provider that guaranteed its customers' prices, and hedged against higher energy costs.	Oil price fell.	Metallgesellschaft's profits rose (fixed output price, cost of buying energy from wholesalers fell).	Value of hedge against higher energy price fell, margin calls. Failure of Metallgesellschaft.	Culp and Miller (1994), Mello and Parsons (1995)
Ashanti Goldfields (1999)	Ashanti Goldfields was a Ghanaian gold producer who hedged against falling gold prices.	Gold price increased.	Revenues rose from selling gold at a higher price.	Value of hedge against lower gold price fell, margin calls. Financial distress of Ashanti.	Adam and Fernando (2006)
Cotton Market Turmoil (2008)	Cotton merchants held inventory by buying physical cotton via forwards, and hedged against cotton price falls.	Cotton price increased.	Inventory of cotton became more valuable.	Value of hedge against cheaper cotton fell, margin calls. Failure of multiple cotton merchants.	Carter and Janzen (2008)
Dash for Cash (2020)	Non-US pension funds and insurers invested in US assets, and hedged against a dollar depreciation.	US dollar appreciated.	Value of non-US institutions' portfolios of US assets rose.	Value of hedge against dollar depreciation fell, margin calls. Forced bond sales.	Czech et al. (2023), Cesa-Bianchi et al. (2023)
UK Bond Market Crisis (2022)	UK pension funds had long duration liabilities, and hedged against the risk of lower rates.	UK rates increased.	Rising rates reduced present value of liabilities for pension funds.	Value of hedge against lower rates fell, margin calls. Forced sales of UK government bonds.	This paper, Pinter (2023), Pinter et al. (2024)
Global Insurers and Pension Funds (2021-3)	Life insurers and pension funds had long duration liabilities, and hedged against the risk of lower rates.	Global rates increased.	Rising rates reduced present value of liabilities for life insurers and pension funds.	Value of hedge fell, margin calls. Liquidity stresses for life insurers and pension funds.	Jansen et al. (2023), Aquilina et al. (2025)

See Appendix A for a detailed narrative description of these episodes.

2.1 LASH Risk Mechanics

We start with the mechanics of LASH risk for interest rates. Consider a financial institution with a portfolio of short-duration assets and long-duration liabilities, as in Figure 1.a. This institution could be a pension fund or insurer, with liabilities to its members that are far in the future. Due to the duration mismatch, a decline in interest rates increases the value of the institution's liabilities more than the value of its assets. Net worth falls—that is, its solvency worsens (Figure 1.b). In contrast, when rates increase, the value of liabilities falls by more than assets, and its solvency improves (Figure 1.c).

How can the institution in Figure 1 hedge duration risk? One approach is to lengthen the duration of its assets. However, a pension fund's or life insurer's liabilities can extend beyond three decades, exceeding the maturity of most outstanding bonds. The fund needs a hedge. One option is to write a derivative contract—such as an interest rate swap—where the institution pays a floating rate in exchange for a fixed rate (as in Figure 2.a). Such a contract will appreciate in value when rates fall, partly offsetting the loss on the rest of the institution's portfolio (Figure 2.b).

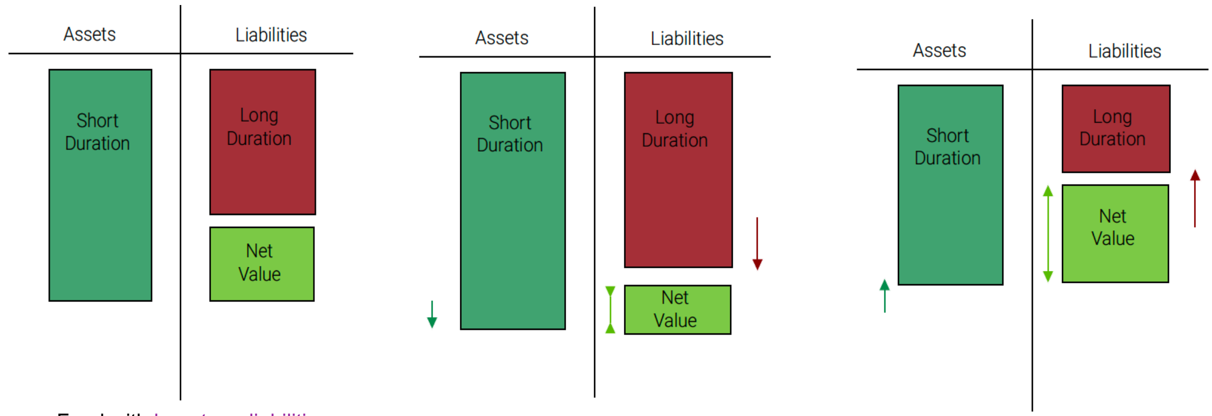
Hedging with interest rate swaps generates liquidity risk as solvency improves—this is LASH risk. When the value of a swap falls, the institution must pay liquid assets to its counterparty equal to the fall in value. This payment is "variation margin".[6]

If the hedge is partial, the institution will become more solvent when interest rates rise. But the same rate increase lowers the value of a receive-fixed swap, triggering variation margin payments to the counterparty (Figure 2.c). The institution, therefore, faces a liquidity need precisely when solvency is improving. This coincidence—deteriorating liquidity alongside improving solvency due to the hedge—is LASH risk materializing.

When LASH risk materializes, liquidity crises can follow. For modest rate increases, institutions may have enough liquid assets to meet variation margin. But large yield rises can generate margin calls that exceed liquid buffers, forcing sales of less liquid assets to raise cash. If those sales include government bonds, the resulting price pressure can push yields higher, increasing mark-to-market losses on swaps and triggering further margin calls—amplifying the liquidity crisis even as solvency improves.

[6]We discuss the institutional details of variation margin in Appendix Section D.

Figure 1 Non-Bank Financial Intermediaries and Interest Rates



a. Fund with long-term liabilities vs assets

b. Rate fall worsens solvency

c. Rate rise improves solvency

2.2 LASH Risk Formalization

We now formalize LASH risk with a model, which generates predictions that will structure our empirical work.

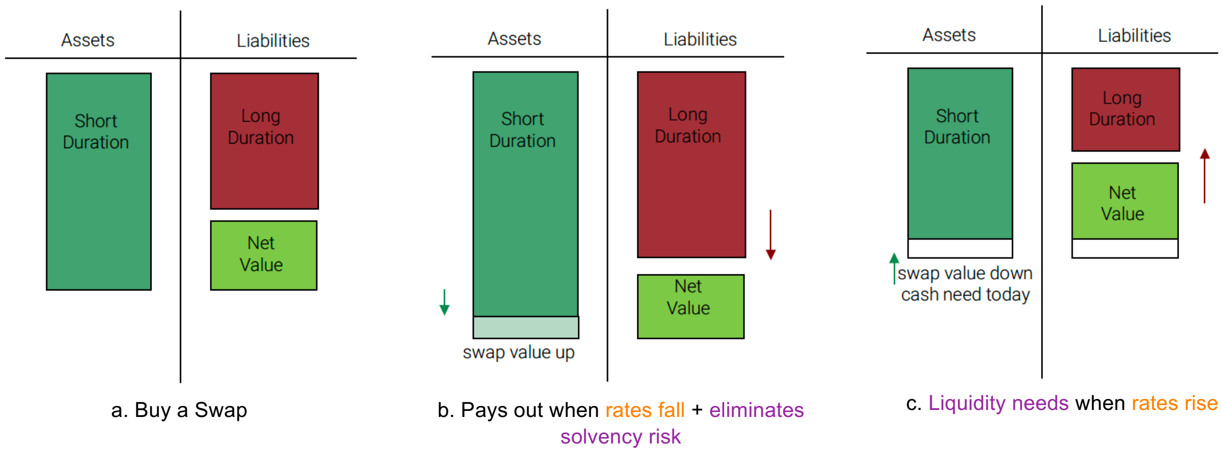
2.2.1 Environment

We consider the investment problem of a non-bank financial institution, or "fund". Time runs from $t = 0, 1, \ldots, \infty$. The fund is endowed with a perpetual liability that requires paying a fixed l in every period. A natural example is a pension fund or a life insurer, which typically have long-duration commitments to their members.

The fund can invest in three assets. First, the fund holds a_t units of a one-period bond, which payoff a_t in period $t+1$. Second, it can hold b_t units of a medium-duration "geometric" bond: holding b_t delivers coupon b_t at $t+1$ and leaves δb_t units outstanding thereafter, so absent trading $b_{t+1} = \delta b_t$, with $\delta \in (0, 1)$. Third, the fund chooses a one-period interest rate swap position s_t, which can be positive or negative. The fund cannot short the bonds, so $a_t \geq 0$ and $b_t \geq 0$.

Asset prices. Asset prices are set by a deep-pocketed marginal investor who is competitive, risk-neutral, and discounts next period payoffs using the one-period stochastic discount factor R_t^{-1}. The marginal investor also derives a non-pecuniary liquidity service η from holding the one-period bond. The fund does not share this non-pecuniary value.

Figure 2 Non-Bank Financial Institutions and Hedging



Let q_t^b denote the price of the geometric bond. The investor values the bond at $q_t^b = \mathbb{E}_t\left[\sum_{j=0}^{\infty} \delta^j \prod_{s=0}^{j} R_{t+s}^{-1}\right]$. Let q_t^l denote the price of a perpetuity paying one every period: $q_t^l = \mathbb{E}_t\left[\sum_{j=0}^{\infty} \prod_{s=0}^{j} R_{t+s}^{-1}\right]$. Last, the liquidity service implies that the price of the short-term bond is given by $q_t^a = R_t^{-1}(1+\eta)$. We assume that the medium-term bond is costly to sell. The fund can sell the geometric bond only at a proportional liquidation cost c, so selling x units yields $(1-c)q_t^b x$.

Swaps are one-period, zero-cost contracts, that are fairly priced. A unit swap delivers at $t+1$ the difference between a floating leg R_{t+1}^{-1} and a fixed leg set at inception to $\mathbb{E}_t[R_{t+1}^{-1}]$.[7] Thus a position s_t delivers realized cash flow $s_t\left(R_{t+1}^{-1} - \mathbb{E}_t[R_{t+1}^{-1}]\right)$. A positive s_t hedges declines in interest rates (higher R_{t+1}^{-1}) and generates losses when rates rise, which we interpret as variation margin.[8]

Fund Value. Define the fund's net asset value (NAV) at the end of period t as the marked-to-market value of its bond holdings net of the continuation value of liabilities: $w_t \equiv q_t^a a_t + q_t^b b_t - q_t^l l$.

Within period t, the fund receives bond payoffs $a_{t-1} + b_{t-1}$, pays the liability flow l, and realizes the prior swap cash flow $s_{t-1}(R_t^{-1} - \mathbb{E}_{t-1}[R_t^{-1}])$. It enters period t with continuation

[7]We have assumed that the swap is written on the inverse of the interest rate for analytical convenience. Buying the swap and receiving the floating leg insures against low rates. In practice, interest rate swaps are written on the level of the rate, and so receiving the fixed leg hedges against low rates.

[8]Note that a multi-period swap that is fully margined would require an exchange of cash flows proportional to the gain or loss on the one-period swap. So the assumption of one-period swaps is a simple way to capture variation margin.

holdings δb_{t-1} of the geometric bond (market value $q_t^b \delta b_{t-1}$). Trading to b_t involves sales $(\delta b_{t-1} - b_t)^+$ that incur proportional cost c. Together, this implies w_t evolves according to

$$w_t = a_{t-1} + b_{t-1} - l + q_t^b \delta b_{t-1} + s_{t-1}\left(R_t^{-1} - \mathbb{E}_{t-1}\left[R_t^{-1}\right]\right) - c q_t^b \underbrace{\max\left\{0, \delta b_{t-1} - b_t\right\}}_{\text{sales of the geometric bond}} - q_t^l l. \quad (1)$$

Liquidity needs. The fund must have sufficient resources in order to cover any losses on its swap position. It is useful to define $m_t \equiv a_{t-1} + b_{t-1} + s_{t-1}\left(R_t^{-1} - \mathbb{E}_{t-1}\left[R_t^{-1}\right]\right) - l$ as liquid resources available to the fund—i.e. coupons from the short- and medium-term bond and the payoff from the swap position, deducting the payment associated with the long-term liability. If liquid resources are positive, then the fund can cover its liabilities including a potential loss on the swap position. If liquid resources are negative, then the fund must sell medium-term bonds. As such, liquid resources and medium-term bonds must satisfy

$$(1-c) q_t^b \max\{0, \delta b_{t-1} - b_t\} \geq -\min[m_t, 0]. \quad (2)$$

The value of sales of the medium-term bond must exceed the liquidity needs of the fund, should these needs be negative.

Fund objective. There is a fund manager in charge of the fund until an exogenous period T.[9] The manager is risk neutral, does not enjoy limited liability and receives compensation in period T (that is negligible compared to the value of the fund) proportional to

$$\pi_T = (1 + \kappa \mathbf{1}(w_T < 0)) w_T. \quad (3)$$

Here, the marginal value to the fund manager of increasing wealth is linear. The marginal value is greater when the fund is in deficit, since $\kappa > 0$. The fund manager maximizes their objective (3) by choosing holdings of swaps, short and medium-term bonds $\{s_t, a_t, b_t\}_{t=0}^T$, subject to the law of motion for net worth (1), the liquidity constraint in (2), and the no-shorting requirement that $a_t, b_t \geq 0$.

2.2.2 Discussion of Main Ingredients

The model combines four ingredients that are natural in the institutional settings we study and are sufficient to generate the key predictions.

[9] The fixed investment horizon is helpful for tractability. An infinite horizon model where the fund manager discounts the future and is compensated in proportion to the current value of the fund every period delivers similar results.

1. **Costs from insolvency.** For the fund, reducing a deficit by \$1 is more beneficial than increasing a surplus by \$1, since $\kappa > 0$ in equation (3). This asymmetry could represent a regulatory penalty. In the UK, for example, pension funds are taxed if they have deficits. These costs could also represent economic factors, such as companies' unwillingness to commit resources to their insolvent pension funds. Finally, the objective resembles "reference dependent" preferences, which may capture relevant behavioral factors (Lian, Ma and Wang, 2019).

2. **Funds can only use swaps to hedge duration risk.** The fund cannot hold assets with long enough duration to hedge duration risk, because the medium-duration asset has lower duration than the perpetual duration liability. The fund can only hedge interest rate risk using swaps.[10] This assumption captures the notion that long-duration assets such as 30-year government bonds are scarce and command high premia. Du et al. (2023) document this scarcity, Greenwood and Vissing-Jorgensen (2018) and Jansen (2021) document the link to bond prices.

3. **Liquid assets command premia.** The fund can insure against liquidity risk by holding short-duration assets. However, these assets command a liquidity premium captured by η in the model. Empirically, liquidity premia are common (see, e.g., Nagel, 2016).

4. **Illiquidity of the medium-term asset.** The medium-term asset has a higher return than the short-term asset but incurs liquidation costs when sold. A reason for these costs could be the constrained broker-dealer balance sheets (Duffie, 2022).

Insolvency costs create a motive to hedge rate risk, but hedging via swaps generates margin-driven liquidity needs. Those liquidity needs are costly to meet because holding liquid assets is expensive and selling the medium-duration bond is inefficient.

To obtain analytical results we make simplifying assumptions about the interest rate process and the fund's problem that we relax in a numerical analysis. First, we assume the interest rate follows a process $R_{t+1}^{-1} = R_t^{-1} + \varepsilon_{t+1}$, where ε_{t+1} is a mean-zero shock to the interest rate with bounded support $[\varepsilon^l, \varepsilon^h]$. The density of ε_{t+1} converges to zero at its bounds and ε^l is high enough so that R_{t+1} is never negative. Finally, $R_{t+j} = \bar{R}$ for all $j \geq 2$. That is, interest rate risk is present only in period $t+1$. It is useful to define $t+1$ net worth if the fund

[10] As we will discuss in Section 2.4, an equivalent hedging strategy involves borrowing short-duration assets to buy the medium-duration asset, i.e. a form of repo contract. This would conflict with the no shorting condition; however, a repo-based hedge can be introduced by assuming that the fund needs to meet its existing liquidity needs at the start of the period before it can borrow further to hedge. The economics of the problem would be very similar so we focus on swaps for simplicity.

neither hedges nor holds short-term bonds, as $y_{t+1}(\varepsilon_{t+1}) \equiv b_t - l + q^b_{t+1}(\varepsilon_{t+1})\delta b_t - q^l_{t+1}(\varepsilon_{t+1})l$. Here, we make explicit that net worth depends on the shock ε_{t+1}. We then make the following assumptions on the fund's problem:

Assumption 1. *(i)* $y_{t+1}(0) > 0$ *and* $y_{t+1}(\varepsilon^h) < 0$*; (ii)* $c < \frac{y_{t+1}(0)}{y_{t+1}(0) - y_{t+1}(\varepsilon^h)}$*; and (iii)* $T = t + 1$*.*

The first part of the assumption requires that, absent hedging, the fund is solvent if rates equal their expected value, whereas the fund is insolvent if rates fall sufficiently far. As such, fund value is neither too great nor too small to render hedging irrelevant. The second and third assumptions are made for tractability. The second ensures that liquidation costs are never large enough at the optimal level of hedging to lead to insolvency. The third assumption, combined with the process for interest rates, allows us to ignore inter-temporal aspects by focusing on a single-period investment horizon.

2.2.3 Predictions of the Model: Liquidity vs. Solvency Risk

The fund uses swaps to trade off solvency risk from rate declines against liquidity risk from rate increases. We define solvency risk as $\Pr(w_{t+1} < 0)$. We define liquidity risk as $\Pr(m_{t+1} < 0)$, i.e. the probability that the fund must sell the medium-duration bond to meet within-period cash needs.

Appendix B.1 derives the first-order necessary condition for the optimal swap position. It equates the marginal benefit of swaps in insolvency states (large rate declines) to the marginal expected liquidation cost in liquidity shortfall states (rate increases that generate swap losses):

$$\kappa \Pr\{w_{t+1} < 0\} \, \mathbb{E}_t[\varepsilon_{t+1} \mid w_{t+1} < 0] = \frac{c}{1-c} \Pr\{m_{t+1} < 0\} \, \mathbb{E}_t[-\varepsilon_{t+1} \mid m_{t+1} < 0] \,. \tag{4}$$

The first order condition shows the fund's incentive to trade off solvency risk against liquidity risk. The term before the equality is the marginal value of holding swaps in states of the world in which the fund has a negative solvency so that $w_{t+1} < 0$. These states occur after unexpected interest rate falls. Therefore, this term represents the benefit of holding swaps, by reducing insolvency when rates fall. The term after the equality is the marginal cost of holding swaps in states of the world where the fund has negative liquidity, so that $m_{t+1} < 0$. In these states, the cost of swaps is the liquidation of medium-term assets. These states happen when interest rates rise, in which case the fund has a loss on its swap position. In these states solvency may improve: the coincidence of better solvency and worse liquidity with rising rates is LASH risk materializing.

We now derive the main three predictions of the model, which we collect in the following proposition.

Proposition 1. *If Assumption 1 holds, the liquidity premium η on the short run asset is sufficiently high, and the maximum realization of the interest rate shock ε^l is sufficiently large, then*

(i) *The fund will partially hedge interest rate risk: the fund will choose an optimal level of hedging $s_t > 0$; but the risk of solvency will be positive, so that $Pr(w_{t+1} < 0) > 0$.*

(ii) *If the interest rate R_t is lower, then the optimal level of hedging s_t increases.*

(iii) *There exists a threshold realization of the interest rate, such that if R_{t+1} exceeds that threshold, the fund will sell medium-duration assets. At this threshold, net worth w_{t+1} is positive and greater than if rates equal their expected level.*

Proof. *See Appendix B.1*

The intuition for the first part of the proposition is straightforward. As we have discussed, the fund holds swaps in order to trade off the solvency risk from falling interest rates against the liquidity risk from rising rates. The proposition establishes that, under our assumptions, the fund does not resolve this trade-off by hedging all of the solvency risk. Since the liquidity premium is large, the fund cannot self-insure with short-term assets. As such, the fund must liquidate medium-term bonds when the loss on the swap is sufficiently large. Since liquidation is costly, the fund does not hold too many swaps, which prevents complete hedging.

The intuition for the second part of the proposition is as follows. By the first part, the fund only partially hedges against interest rate risk. Therefore falling interest rates lower the solvency of the fund. Since insolvency is costly and nearer, the fund has a greater incentive to hedge against interest rate risk by raising its holdings of swaps. Formally, for a given s_t lower rates raise the left hand side of equation (4) but have no impact on the right hand side. As such, low rates make the fund raise its swap holdings.

The third part of the proposition is also simple. A large increase in interest rates implies a large payment is required to cover the loss on the swap position. This necessarily exhausts the fund's holdings of liquid assets. As such, the fund must sell medium-term bonds to satisfy the margin call. Liquidation of the medium-term asset is what we term a "liquidity crisis". However, the underlying solvency of the fund will have improved—in the sense that the fund has higher value than if interest rates had not increased.

Last, our analytical results make strong assumptions for tractability. In Appendix B.2, we explore a calibrated version of the model with $T > t + 1$ and interest rate risk at all horizons and show that with reasonable liquidity premia, swaps holdings and LASH risk indeed rises as interest rates fall. For numerical results we simply assume the rate is i.i.d. Our result also hinges on hedging taking place using swaps, or other *linear* hedging strategies. We elaborate on this aspect of the model in Appendix B.3. In the coming sections, we will confront the three predictions of our model with data.

2.3 LASH vs. Other Liquidity Risk

Our framework shows that LASH risk is different from other forms of liquidity risk. Consider, for instance, liquidity risk from maturity transformation and bank runs (Diamond and Dybvig, 1983). In this case, the risk of a bank run is linked to the bank's long-term and illiquid assets versus their short-term and callable liabilities to savers. However, LASH risk is independent from callable claims. In our example of a pension fund, liabilities are long term and assets are shorter term—the opposite pattern of the traditional bank.

LASH risk is also distinct from liquidity risks associated with rolling over short-term debt (e.g., Calvo, 1988; Cole and Kehoe, 2000; Morris and Shin, 2004; He and Xiong, 2012; Aguiar et al., 2022). In our example, LASH risk occurs even though liabilities are long term and debt is not rolled over.

Finally, LASH risk differs from models in which liquidity and solvency deteriorate together. In Brunnermeier and Pedersen (2009), an initial loss reduces net worth, tightens funding constraints and margin requirements, forces asset sales, depresses prices, and thereby generates a liquidity spiral. With LASH risk, the direction of the solvency comovement is reversed: margin-driven liquidity needs arise in states where solvency improves because the hedge loses value precisely when the underlying balance sheet gains.

2.4 Beyond Swaps

We now discuss how LASH risk arises with other hedging instruments. Beyond interest rate swaps, an institution can also alter its interest rate exposure by financing longer-duration assets with short-term borrowing. For example, it can borrow via a repurchase agreement (repo) and use the proceeds to purchase longer-duration bonds. Economically, this position mirrors a swap: the institution pays a short-term floating rate on its borrowing and receives a longer-duration fixed-rate cash flow on the asset position.

Repo borrowing can generate LASH risk for the same reason as swaps: when interest rates rise and bond prices fall, collateral values are marked-to-market and the borrower may face margin calls that require immediate cash. In our framework, repo-based hedging is therefore closely related to swap-based hedging—both create positions that benefit from falling rates but can require liquidity when rates rise. Through the lens of our model, repo borrowing is near-equivalent to swaps: it is enough to assume that repo funding cannot be adjusted frictionlessly at the moment margin is due, so that liquidity risk remains present. Section 6.3 presents empirical evidence for this inflexibility, and Appendix B.4 shows how a repo-based hedge is near-equivalent in the model.

Our empirical work will treat LASH risk from repos and swaps equally, and we will abstract from the choice of hedging strategy. However, in the UK context, pension funds that are fully- or over-funded appear to prefer to use repo-based hedging as the relevant payoffs are more closely linked to the discount factor used compute the present value of pension fund liabilities – i.e. long-term government bond yields. In contrast, interest rate swaps typically use money market rates as the underlying interest rate, so they are an imperfect hedge. Underfunded funds may lack the assets to fully hedge via repo. As described in Klingler and Sundaresan (2019), this can induce reliance on swap-based hedging, pushing swap spreads deep into negative territory even when long-term bonds are scarce.

The fund can hedge the risk from long-term liabilities and short-term assets with another strategy: it can hold a stake in a second fund that has the opposite duration structure, that is, short-term liabilities and long-term assets. In the context of pensions, particularly in the UK, this latter fund is known as a Liability-Driven Investment (LDI) fund. The LDI fund borrows with repo to buy longer-duration assets (or engages in equivalent interest rate swap transactions). The payoff from holding an equity stake in the LDI fund replicates the payoff from employing the hedging strategy directly. Again, lower interest rates raise solvency risk, while higher interest rates raise liquidity risk. LDI funds benefit smaller pension funds, which lack the scale to manage hedging strategies in-house, and thus outsource hedging to the LDI funds, often in "pooled" entities that include assets from several pension funds. Pension funds are subject to cash calls to provide liquidity to LDI funds that they own in the case of margin calls that the LDI fund cannot cover itself.[11]

3 Data and Measurement of LASH Risk

This section discusses our data sources and how we use the data to measure LASH risk.

[11] We discuss institutional details of the UK pension fund system in Appendix Section C.

3.1 Data Sources and Coverage

To measure LASH risk for interest rates, we assemble four datasets: (i) the universe of UK government bond (gilt) transactions; (ii) the universe of gilt repo transactions; (iii) trade-repository records on sterling interest rate swaps that we use to reconstruct weekly outstanding positions; and (iv) hand-collected UK pension fund balance sheet data. Our baseline analysis focuses on the common sample window available across these sources, January 2019 to March 2023.

Bond market. To analyze trading in the UK bond market, we use the transaction-level MiFID II database maintained by the UK's Financial Conduct Authority (FCA). The MiFID II data provide detailed reports of all secondary-market trades of UK-regulated firms or branches of UK firms regulated in the European Economic Area (EEA). Given that all bond dealers are UK-domiciled and hence FCA-regulated institutions, our data cover virtually all transactions in the market. Each transaction report contains information on the transaction date and time, ISIN (a unique identifier for each bond), execution price, transaction size, and the legal identities of the buyer and seller. We focus on UK government bonds (gilts); from here on, "bond" refers to gilts unless stated otherwise.

Repo Market. The Bank of England's Sterling Money Market data (SMMD) is a transaction-level dataset covering the sterling unsecured and secured (gilt repo) money markets. The data are obtained from dealers in the respective money markets and have been collected since 2016. The data cover 95% of activity in which a bank or dealer is a counterparty, but the data do not capture the small segment of non-bank to non-bank repo transactions. We are again able to identify the identity of the counterparties, the collateral ISINs associated with each transaction, the transaction size, and the execution price.

Interest Rate Swap Market. To analyze the interest rate swap positions, we use transaction-level data from two European Markets Infrastructure Reporting (EMIR) Trade Repositories, DTCC and LSEG Regulatory Reporting Limited (previously Unavista). We collect weekly positions on outstanding over-the-counter (OTC) GBP interest rate swap (IRS) and overnight index swap (OIS) trades where at least one of the counterparties is a UK entity.[12] The IRS dataset contains trade-level information on the counterparties'

[12] We retrieve the data via the Bank of England's access to the mandatory reporting of the UK European Markets Infrastructure Regulation (UK EMIR). More details on the reporting obligation can be found here. For pre-2021 data (reported under EU EMIR), the Bank of England had access to (i) trades cleared by a CCP supervised by the Bank, (ii) trades where one of the counterparties is a UK entity, (iii) trades where the derivative contract is referencing an entity located in the UK or derivatives on UK sovereign debt, (iv) trades where the Prudential Regulation Authority (PRA) supervises one of the counterparties. For post-2020 data, the Bank of England has access to all data reported to trade repositories under UK EMIR.

identities, notional, currency, floating rate, the direction of trade, maturity, and execution date. Our cleaning procedure follows Khetan et al. (2023) with additional steps tailored to constructing and interpreting outstanding positions in our setting.

In addition, to construct discount curves and map yield changes into swap and bond valuation changes underlying our LASH-risk measures, we use Bank of England data on OIS and gilt yield curves, together with security-level daily modified duration for gilts from Bloomberg.

Pension Fund Balance Sheets. We construct, to the best of our knowledge, the largest dataset detailing individual UK pension fund balance sheets. We hand-collect data from annual reports and newsletters for 113 individual pension funds from 2017 to 2023, covering around 50% of the UK pension sector by actuarial asset value in 2022.[13] Our database includes information on net investments, cash, bonds and derivative holdings. Tables II.1 and II.2 summarize the cross-section of actuarial assets and liabilities, and the evolution of funding ratios over time.

3.2 Measurement: Interest Rate LASH Risk for Non-Banks

We now describe how we measure LASH risk arising from interest rate hedging. The object we construct is a contract-level sensitivity of margin calls to interest rate movements, which we then aggregate to the institution and sector level. Analogous steps can be used to measure LASH risk from other hedges—for example, from FX hedging—by replacing interest rate valuation sensitivities with those relevant for the underlying risk factor.

General Concept. We wish to measure how margin calls of a given contract change after a shock to interest rates. As such, given a shock to interest rates R_t, LASH risk for hedging contract i is

$$LASH_{i,t} \approx \Lambda_i \times \frac{\partial NPV_{i,t}}{\partial R_t}, \tag{5}$$

where $NPV_{i,t}$ is the net present value of the hedging contract. For a swap, $NPV_{i,t}$ is the present value of the floating leg minus the fixed leg. For a repo contract, $NPV_{i,t}$ is the value of the repo collateral. One can interpret $\partial NPV_{i,t}/\partial R_t$, sometimes referred to as dollar duration or DV01, as the effect of a uniform shift in the yield curve on the present value of the hedging contract. Λ_i captures by how much margin increases as the NPV of the

[13] There is limited fund-level data on UK pension fund balance sheets. The closest exercise in collecting UK data is done by Konradt (2023), covering 12 UK pension funds worth \$300bn in asset value. In 2022, we observe 91 pension funds worth £1tn in actuarial assets, out of the total of £2.1tn in the UK pension fund sector in Q4 2022. Our sample also includes 20 out of the largest 25 pension funds by assets. Calculations are based on ONS data.

contract changes, which may differ based on the contract type. For both swaps and repos on government debt, the typical contract features $\Lambda_i \approx 1$, so we use this value.[14] Setting Λ_i as a constant abstracts from changing margin requirements or in repo haircuts in response to a change in rates. Internet Appendix I elaborates on how the specific steps to compute (5) for repos and interest rate swaps.

For a given institution j that holds $Q_{i,j,t}$ of a given hedging contract, its aggregate LASH risk is given by

$$LASH_{j,t} = \sum_i Q_{i,j,t}\text{LASH}_{i,t}. \tag{6}$$

Letting $Q_{i,t}$ denote the aggregation of contracts across institutions, aggregate LASH risk is given by

$$LASH_t = \sum_i Q_{i,t}\text{LASH}_{i,t} = \sum_j LASH_{j,t}, \tag{7}$$

where $Q_{i,t} \equiv \sum_j Q_{i,j,t}$.

Two observations are in order. First, contracts with long maturity have higher LASH risk, since their NPV is more sensitive to changes in interest rates. Second, LASH risk goes in both directions—firms can receive or pay liquidity, depending on the direction of their exposure and the price change of the underlying instrument. If the contract value $Q_{i,t}$ decreases (increases) from the perspective of institution j, then the firm is obliged to post (receive) margin. For example, pension funds are exposed to liquidity demands when yields rise, whereas their counterparties (mainly dealer banks) have to post margin when rates fall.

Given that each contract involves two counterparties, the aggregate measure of $LASH_t^A$ for all institutions in the economy is close to zero. When we document positive LASH risk for the non-bank financial sector, it implies that another set of agents in the economy has negative LASH risk exposures (in the UK, for example, that would be the banking sector—see, e.g., Khetan et al., 2023).

Mechanical versus Discretionary LASH risk. A key challenge is that $\partial NPV_{i,t}/\partial R_t$ in equation (5) is not constant: by convexity, the interest rate sensitivity of long-dated cash flows increases when rates are low. Since we study how institutions *choose* LASH risk as rates vary, we must account for this automatic link. We decompose the change in aggregate LASH risk into a "mechanical" component—changes in contract-level interest rate sensitivity

[14] Margin requirements on interest rate swaps are typically set so that the variation margin equals the change in the value of the swap, while repo haircuts on government debt are fairly close to zero (for example, the average gilt repo haircuts for LDI funds were only around 25bps in the first three quarters of 2022, see Ivan, Lillis, Maqui and Salazar, 2024). So long as Λ_i is homogeneous across investors its exact value will not play an important role in our empirical analysis.

holding quantities fixed—and a "discretionary" component—changes in quantities holding contract sensitivities fixed:

$$\overbrace{\Delta \sum_i Q_{i,t}\text{LASH}_{i,t}}^{\text{aggregate change}} = \underbrace{\sum_i Q_{i,t}\Delta\text{LASH}_{i,t}}_{\text{mechanical change}} + \overbrace{\sum_i \text{LASH}_{i,t-1}\Delta Q_{i,t}}^{\text{discretionary change}}. \tag{8}$$

The mechanical component captures convexity. The discretionary factor captures how the financial institutions shift their allocation of hedging, $Q_{i,j,t}$, towards contracts i with ex ante higher or lower LASH risk.[15] One can obtain a similar measure of discretionary LASH risk at the institution level.

4 LASH Risk from Interest Rates: Descriptive Facts

This section shows that, consistent with our model, institutions with long-dated liabilities like pension funds and insurers take on significant LASH risk. We provide additional descriptive facts about the nature of this LASH risk. Finally, we show that despite LASH risk, pension funds are partially hedged, meaning their net worth rises with interest rates.

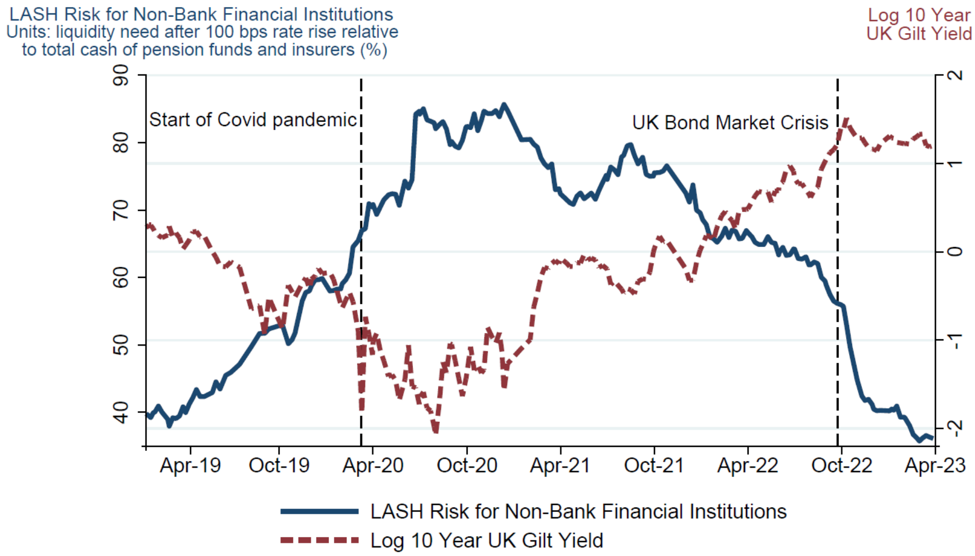
4.1 LASH Risk—Descriptive Facts

This section presents four descriptive facts about our measure of LASH risk for non-bank financial institutions and sterling rates. In brief, we find that (i) LASH risk is large and higher when interest rates are low; (ii) movements in LASH risk are largely due to discretionary rather than mechanical reasons; (iii) LASH risk is large for both interest rate swaps and repo contracts; and (iv) LASH risk is concentrated in the pension fund sector, including LDI funds.

i. LASH risk is large, and higher when interest rates are low. Figure 3 demonstrates this fact, by reporting aggregate LASH risk at weekly frequency, in the non-bank financial sector, from 2019 to 2023. To give a sense of scale, we normalize LASH risk by the cash holdings of UK pension funds and insurers (who, as we will see, are the main holders of LASH risk). The units indicate that at the peak, a 100bps increase in interest rates would have induced liquidity needs that would almost deplete the entire cash positions of both sectors—in other words, LASH risk is very large. For context, although a 100bps

[15] This decomposition is exact as, to be conservative, we have assigned second-order terms, i.e. $\Delta Q_{i,t}\Delta\text{LASH}_{i,t}$, to the mechanical change.

Figure 3 LASH RISK: NON-BANK FINANCIAL INSTITUTIONS



NOTE. Estimated liquidity needs after a 100bps rise in interest rates, expressed as a share of total cash holdings of UK pension funds and insurers (%). The series corresponds to aggregate non-bank LASH risk, $LASH_t$, constructed from outstanding repo and swap positions as described in Section 3.2. Cash is from the UK flow of funds and is defined as currency, deposits, and holdings of money market fund liabilities.

interest rate increase is significant, it is smaller than the 130bps trough-to-peak increase in the 30-year gilt yield during the 2022 UK bond market crisis. Moreover, as predicted by our framework, LASH risk moves inversely with interest rates. The figure also plots the log of the 10-year gilt yield (dashed line, right axis). When long-dated government bond yields are relatively low, as in 2020, LASH risk is relatively high.

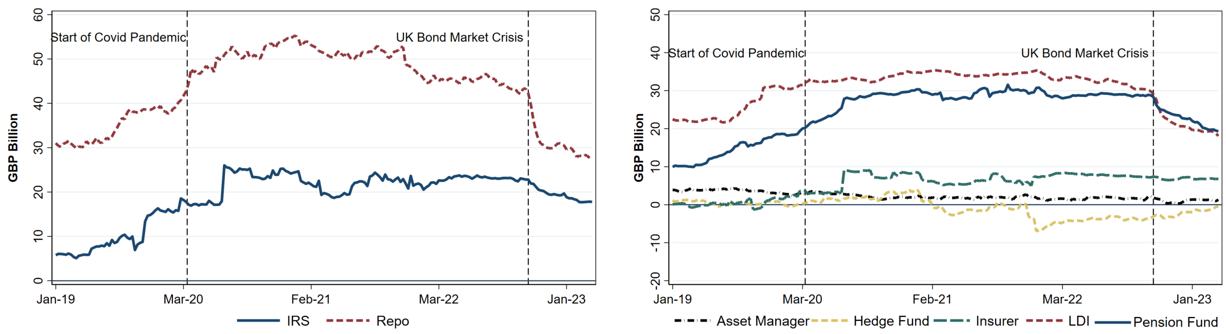
The relationship between interest rates and LASH risk also holds outside the UK. Internet Appendix Figure II.9 documents a similar pattern for US life insurers: the liquidity risk associated with interest rate hedging co-moves with the level of interest rates, again consistent with the predictions of our framework.

ii. Movements in LASH risk are largely due to discretionary rather than mechanical reasons. Recall that LASH risk can vary for two reasons: first, institutions might reallocate funds towards instruments with higher LASH risk; and second, the LASH risk of individual contracts mechanically rises as interest rates fall due to convexity. Internet Appendix Figure II.8 demonstrates that discretionary effects dominate—the total LASH risk is shown in blue, and the discretionary component in red. The two series co-move closely. Therefore, movements in LASH risk over time primarily reflect how institutions reallocate funding and hedging towards instruments with higher LASH risk.

Figure 4 LASH: Swaps vs. Repo and Sectoral Breakdown

(a) Swaps vs. Repo

(b) Sectoral Breakdown



NOTE. Panel (a) shows the evolution of the discretionary LASH risk by instrument in £bn for all non-banks, separately for swaps versus repo. Panel (b) shows the evolution of the discretionary LASH risk across different sectors in £bn, for pension funds, insurers, LDI funds, hedge funds and asset managers, respectively.

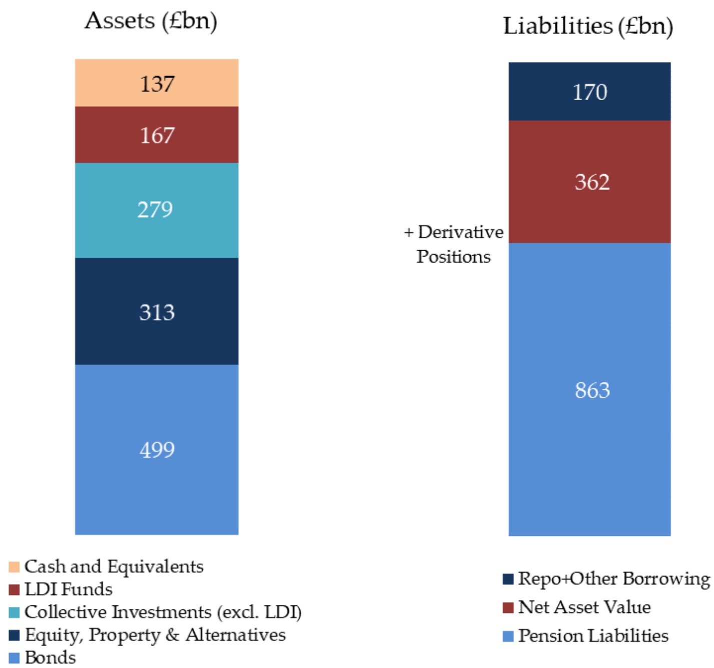
The third and fourth facts describe where LASH risk concentrates.

iii. LASH risk is large for both interest rate swaps and repo contracts. These are the two primary hedging strategies that we consider, both prevalent throughout the non-bank financial system. In practice, both strategies generate significant LASH risk. Figure 4a reports this result. In the figure, the dashed red line captures LASH risk for repo contracts, whereas the blue solid line is LASH risk for swaps. Both swap and repo exposures are large, and the LASH risk from repo tends to be £20-30bn higher than the LASH risk from swaps.

iv. LASH risk is concentrated in the pension fund and, to a lesser extent, the insurance sector. Figure 4b displays this result. In the figure, we disaggregate LASH risk across five sectors, namely regular pension funds, LDI funds, insurers, asset managers, and hedge funds. Broadly defined, LDI funds belong to the pension fund sector. Considering LDI funds and regular pension funds jointly, it is apparent that the broad pension fund sector is the primary holder of LASH risk for interest rates. Insurers have a smaller but positive amount of LASH risk. Traditionally life insurers also have a smaller duration gap than pension funds. Asset managers and hedge funds, by contrast, hold little net LASH risk in sterling rates over the sample, consistent with having limited structural duration exposure in aggregate.

Figure 5 puts this finding in context by presenting the aggregate balance sheet of UK defined benefit private pension funds at the end of 2022 (see Appendix C for additional institutional details). On the asset side, major components include equities/alternatives and bonds, while liabilities are dominated by long-dated pension obligations; repo borrowing and LDI investments appear as additional balance sheet items linked to interest rate hedging. It

Figure 5 UK Pension Funds: Aggregate Balance Sheet



NOTE. Calculations are based on 2023 ONS data and 2023 PPF 7800 data.

also highlights that interest rate hedging activity is quantitatively important. Swaps—the third main hedging channel—are held off balance sheet; Internet Appendix Figure II.5 reports aggregate swap notionals. Taken together, the pension sector's interest rate hedging footprint (direct and intermediated via LDI vehicles) is large relative to sectoral cash holdings and pension liabilities.

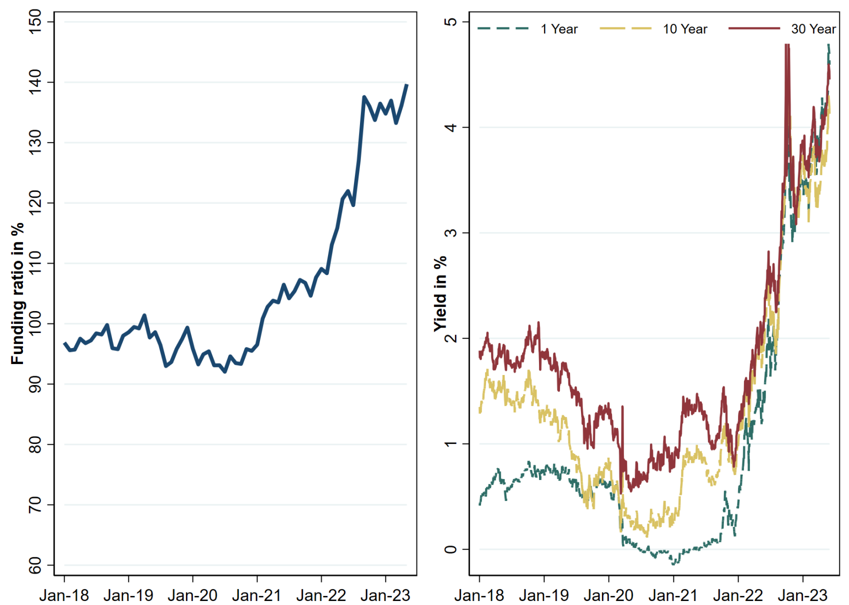
In the sections that follow, we provide baseline results for the full non-bank sector to exploit the cross-institutional heterogeneity in exposure to interest rates. For each analysis, we also report specifications that focus only on the pension fund sector and show that all main findings are preserved.

4.2 Partial Hedging of Interest Rate Risk

Our framework predicts that pension funds partially hedge interest rate risk by taking on LASH risk. We have established the presence of LASH risk and that the funds hedge. We now show that the hedging is partial—as rates rise, pension fund solvency improves.

Pension fund solvency is commonly summarized by the funding ratio, defined as the value of assets relative to the present value of liabilities, where liabilities are discounted using long-dated bond yields. Figure 6 shows that the aggregate funding ratio rose from around 90%

Figure 6 Pension Funds' Funding Ratios and Bond Yields



NOTE. The left panel shows the aggregate funding ratio (defined as total market value of assets divided by market value of liabilities) of UK pension funds in %. Source: Pension Protection Fund 7800 Data. The right panel displays the yields of UK government bonds (gilts) at different maturities in %.

in 2020 to almost 140% at the end of 2022. Over this period, interest rates rose. As such, despite hedging against some interest rate risk, pension funds are not fully hedged.

5 Low Interest Rates and High LASH Risk

Our descriptive evidence documents a striking aggregate pattern: LASH risk is high when interest rates are low. This pattern is what our conceptual framework predicts. Falling rates reduce solvency, raise demand for hedging, and increase LASH risk. In this section, we test this mechanism using cross-sectional variation in institutions' solvency exposure to interest rate movements. Consistent with our predictions, the impact of rate cuts on LASH risk is strongest for institutions whose solvency weakens the most after the cut. The result is robust across a range of specifications, including demanding designs that absorb time-invariant institution characteristics in the sensitivity of hedging to the level of rates.

5.1 Measures of Net Duration

We start by identifying the institutions whose solvency falls the most after rate cuts. The key object is the duration gap between assets and liabilities, or net duration, which governs how solvency responds to changes in interest rates. Net duration is difficult to calculate for all institutions in our sample, and so we will study three alternative measures. Each will allow us to explore different dimensions of the data.

Our first measure, which we refer to *trading duration*, proxies for asset duration using the duration of the bonds the institution trades. Specifically, we consider the weighted-average modified duration of an institution's bond trades in the year prior to the start of our sample:

$$\text{Trading Duration}_{j,t} = \sum_{i \in \mathcal{I}} \text{Weight in 2018 Trades}_{j,i,0} \times \text{Bond Modified Duration}_{i,t}, \qquad (9)$$

where i indexes securities in $\mathcal{I}$, Weight in 2018 $\text{Trades}_{j,i,0}$ is bond i's share in institution j's gross trades in the year prior to the beginning of our sample, and Bond Modified $\text{Duration}_{i,t}$ is its modified duration at quarter t. The trade share weights are held fixed; the measure is time-varying only because bond duration varies with the level of interest rates due to convexity. This measure has the advantage of being available for all institutions in our sample.

When rates fall, long-duration bond positions experience larger valuation gains than shorter-duration positions. For a given liability profile, these larger gains cushion solvency relative to institutions whose assets are shorter-duration. Consequently, absent a strong offsetting correlation between asset and liability duration across institutions, trading duration and net duration should be positively correlated. We can validate this in a subsample of pension funds where we observe hand-collected balance sheet information. For these institutions, we construct a fund-level duration gap measure. As described in Appendix E, we estimate the sensitivity of each fund's funding ratio to changes in the ten-year bond yield over our sample. We define the institution's *Duration Gap* as the negative of this estimated slope; under this convention, more negative values indicate a wider gap and greater solvency exposure to interest rate movements. This measure is estimated once per fund and treated as time-invariant. Appendix Figure E.1 plots the estimated duration gap against our trading duration measure at $t = 0$, and shows a clear positive relationship: funds with shorter trading duration exhibit wider (more negative) duration gaps, consistent with their solvency being more sensitive to rate movements.

We use this measure, constructed from the hand-collected balance sheet data, as our second measure of net duration. Conceptually it is closer to the object of interest, but it is available only for a subset of institutions and is based on ex-post data.

Our third measure is the duration of the gilts that institutions pledge as repo collateral. Specifically, we define *Repo Collateral Duration* analogously to equation (9), using pre-sample repo collateral weights instead of trading weights. This measure has the advantage that it reflects holdings rather than trading flows, mitigating concerns that an institution's long-duration positions were accumulated before our trading data began, but comes with the caveats that only a subset of institutions in our sample access repo markets and that pledged collateral need not be representative of the institution's overall bond portfolio.

5.2 Regression: Low Rates and LASH Risk in the Cross-Section

Institutions with wider duration gaps experience larger declines in solvency as rates fall. Our framework predicts correspondingly larger increases in LASH risk for these institutions. To test this idea, we estimate the following quarterly panel regression:

$$\Delta LASH_{j,t}^{Disc.} = \beta_1 \Delta Yield_t^{10Y} + \beta_2 \Delta Yield_t^{10Y} \times \text{duration measure}_{j,t} + \text{fixed effects} + \varepsilon_{j,t}, \quad (10)$$

where $\Delta LASH_{j,t}^{Disc.}$ is the quarterly change in institution j's discretionary LASH risk at the end of quarter t, $\Delta Yield_t^{10Y}$ is the quarterly change in the 10-year nominal government bond yield (in percentage points), and duration measure$_{j,t}$ is standardized so that the cross-sectional standard deviation is one. Therefore, β_1 captures the average sensitivity of LASH risk to yield changes, while β_2 captures how this sensitivity varies with a one standard deviation change in duration. We apply the inverse hyperbolic sine transformation to the dependent variable, which delivers a log-like coefficient interpretation while remaining well-defined when LASH risk is negative. Standard errors are clustered at the institution level.

The coefficient of interest is β_2, which captures whether yield changes induce a larger increase in LASH risk for institutions whose solvency is more interest rate sensitive. Our identification assumption is that the duration measure is uncorrelated with other omitted institution-level characteristics that differentially shape how hedging (and thus LASH risk) responds to interest rate changes; we will probe this identification assumption with balance tests, and with increasingly stringent fixed effects. In our most demanding specification, we will control for all time-invariant institutional characteristics governing the relationship between LASH risk-taking and interest rates.

We support the identification assumption with balance tests on observables. Appendix Table E.2 reports balance statistics for the subsample of pension funds for which we have hand-collected balance sheet information. Along our duration proxies, we do not find systematic differences in institution size, portfolio composition (e.g., bond–equity ratios), liquidity holdings, or aggregate use of derivatives and other hedging activity. While these tests cannot rule out all unobserved differences, they mitigate the concern that the duration measures are

Table 2 RATES AND INSTITUTION-LEVEL LASH RISK

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					$\Delta LASH^{Discretionary}$				
$\Delta Yield^{10Y}$	−1.61***								
	(0.48)								
$\Delta Yield^{10Y}$ × Trading Duration	0.69**	0.69**	0.72**	0.60					
	(0.32)	(0.32)	(0.35)	(0.49)					
$\Delta Yield^{10Y}$ × Duration Gap					2.42***	3.49***			
					(0.89)	(1.20)			
$\Delta Yield^{10Y}$ × Repo Collateral Duration							0.94**	0.99**	1.12*
							(0.41)	(0.45)	(0.62)
Observations	4526	4526	4526	4526	733	733	3526	3526	3526
R squared	0.025	0.031	0.064	0.123	0.105	0.103	0.032	0.055	0.110
Model	OLS	OLS	OLS	OLS	OLS	IV	OLS	OLS	OLS
Number of Institutions	341	341	341	341	51	51	243	243	243
Kleibergen-Paap F-statistic						7.14			
tF-adjusted SE						1.72			
Time FE	no	yes	yes	yes	yes	yes	yes	yes	yes
Institution FE	yes	yes	yes	yes	yes	yes	yes	yes	yes
Institution-Yield Level FE	no	no	yes	yes	no	no	no	yes	yes
Institution-Yield Slope FE	no	no	no	yes	yes	yes	no	no	yes

NOTE. As dependent variable, for each investor, we compute the quarterly change in the discretionary LASH Risk measure. In columns (1)-(4), the explanatory variable is the quarterly change in the 10-year gilt yield interacted with institution j's gilt trading-based asset duration. This duration measure is constructed using trade weights from the institution's gilt repo transactions in 2018, which are combined with the time-varying modified duration of the underlying gilts. The dependent variable is transformed using the inverse hyperbolic sine method; yield changes are expressed in percentage points; and modified duration is standardized. We include investor, quarter, institution-yield level (10-year gilt yields) and institution–yield-slope (10-year minus 2-year gilt yields) fixed effects. In column (5), for a sample restricted to pension funds, we replace the asset duration measure with the negative of the sensitivity of a pension fund's funding ratio to 10-year gilt yield changes, which serves as a proxy for the fund's net duration gap. We also include leverage (log of net repo borrowing) and size (log of total assets), each interacted with the quarterly change in the 10-year gilt yield, as additional controls. Column (6) instruments pension funds' net duration gap with our gilt trading-based asset duration measure. We report the Kleibergen-Paap F-statistic and the tF-adjusted standard error for the 90% confidence level in column (6). Regressions in columns (5) and (6) are weighted by fund size. In columns (7) to (9), we calculate institution j's modified asset duration based on portfolio weights from the investor's gilt repo portfolio at the beginning of the sample, and then interact these weights with the time-varying modified duration of the individual gilts. Standard errors are clustered at the institution level. *** p<0.01, ** p<0.05, * p<0.1. Coefficients corresponding to the constant, control variables and fixed effects not reported.

simply proxying for obvious institution types with mechanically different responses to rate cuts.

Columns (1)–(4) of Table 2 present the results using trading duration. The estimates are economically large, statistically significant, and consistent with the mechanism. Column (1) estimates a negative value of β_1, indicating that lower yields are associated with higher discretionary LASH risk on average. The coefficient implies that a 100bps quarterly decline in the ten-year gilt yield is associated with roughly a 80% increase in institution j's discretionary LASH risk.[16] The interaction coefficient, β_2, indicates that this sensitivity is weaker for institutions with longer-duration assets. Quantitatively, for an institution with trading duration one standard deviation above the mean, the implied increase following a 100bps yield decline is about 60%. Column (2) adds time fixed effects, so that identification comes entirely from cross-sectional differences in duration interacting with the common yield change; β_2 is similar.

In column (3), we exploit the time variation in the duration proxy to include institution $\times$ yield-level interactions. This absorbs all time-invariant institution-specific heterogeneity in how the level of rates maps into LASH risk-taking. Identification then comes from differential time variation in trading duration across institutions—driven by the convexity of the bonds in their initial trading baskets—which shifts how a given yield change translates into solvency exposure. Even in this demanding specification, column (3) delivers a similar estimate of β_2.

Column (4) further allows institutions to have differential sensitivity to changes in the slope of the yield curve (the 2-year to 10-year spread). The interaction estimate becomes statistically imprecise in this saturated specification, but the point estimate for β_2 is close to column (3). This pattern suggests that the main result is unlikely to be driven by differential responses to changes in the slope of the yield curve.

Column (5) of Table 2 uses our second measure, net duration from the hand-collected balance sheet data, for the subsample in which it is available. Since this measure is time-invariant, we cannot include institution $\times$ yield-level fixed effects. However, we include as controls leverage (log of net repo borrowing) and size (log of total assets) interacted with the quarterly change in the 10-year gilt yield. The β_2 coefficient remains positive, and its magnitude increases. The likely reason is that the second measure of net duration is less noisy than the first, albeit in a substantially smaller sample.

The fund-level duration gap measure is estimated rather than observed. Moreover, it is constructed from funding ratio responses over our sample period, which may reflect behavior

[16] Because the dependent variable is inverse hyperbolic sine-transformed, coefficients are not directly interpretable as percent effects. We therefore report the log-like approximation $100 \times (\exp(\beta) - 1)$.

after the start of the sample. Both features can attenuate the estimated interaction effect and, in the latter case, lead to endogeneity. In column (6), we therefore implement an IV strategy that uses $t = 0$ trading duration as a predetermined instrument for the duration gap (and, correspondingly, for its interaction with yield changes). This approach isolates variation in interest rate exposure that is plausibly unrelated to behavior after the start of the sample, and avoids attenuation bias. Consistent with this narrative, the estimated β_2 increases in magnitude in column (6). Appendix Table E.1 reports the first stage and confirms a positive relationship between the two duration measures. Given that instrument strength is moderate, we also report weak-IV robust (tF-adjusted) 90% inference following Lee et al. (2022); the interaction effect remains statistically significant under this adjustment.

Columns (7)–(9) examine our third duration proxy, based on the duration of gilts pledged as repo collateral, for the subset of institutions that are active in the repo market. We mirror the specifications from the trading-duration analysis—adding time fixed effects, then institution × yield-level interactions, and then allowing differential sensitivity to yield-curve slope changes. The estimates are similar and slightly larger in magnitude, and the interaction remains statistically significant even under the richest fixed effects specification.

Overall, the panel evidence supports the mechanism in our framework: declines in yields lead to larger increases in LASH risk for institutions whose solvency is more exposed to interest rate movements. This conclusion is robust across alternative duration proxies and even when we control for time-invariant factors mediating how rate cuts lead to LASH risk. Taken together, these results complement the aggregate time series patterns in the previous section and suggest that low interest rates cause higher LASH risk.

6 Consequences: LASH Risk and Liquidity Crises

We now show that, consistent with our conceptual framework, when LASH risk materializes, it can lead to liquidity crises. These crises materialize even if solvency rises at the same time. We focus on the 2022 UK bond market crisis. We emphasize that LASH risk was not itself the "root cause" of this crisis. Instead, the root cause was a sudden, initial rise in rates—which was then amplified by LASH risk.

6.1 Background: 2022 UK Bond Market Crisis

Background. On 23 September 2022, the Chancellor at the time, Kwasi Kwarteng, presented a "Mini-Budget" proposal to the UK Parliament. The abrupt change in the fiscal stance initiated a sharp rise in interest rates.

Over the subsequent days, there was a combination of (i) margin calls on term repo and swap positions, (ii) sales of bonds in order to raise liquidity, and (iii) further rises in interest rates and then further margin calls. These three factors collectively characterized the liquidity crisis. From trough-to-peak during the crisis, 30-year gilt yields rose by 130bps in a matter of days. In total, pension and LDI funds sold nearly £30bn in the period between September 23 and October 14 (see Internet Appendix Figure II.10 and Pinter, 2023).

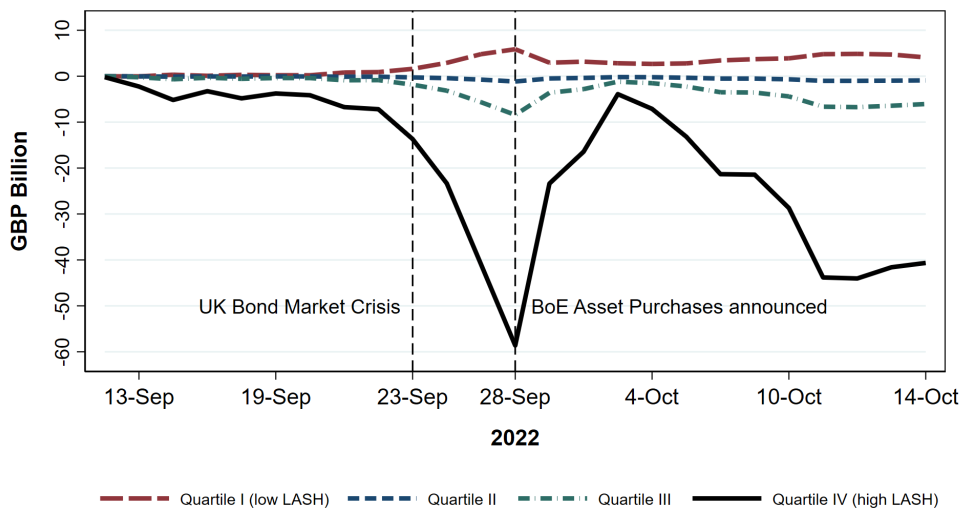
As the liquidity crisis intensified, the Bank of England intervened to safeguard financial stability. The Bank announced temporary and targeted purchases of long-dated gilts on 28 September (scheduled to end on 14 October). This appeared to help stabilize yields and provide time to funds to meet margin calls and adjust their portfolios (Hauser, 2023b; Alexander et al., 2023). Importantly, liquidity needs arose even as the solvency of the pension fund sector improved—the present value of pension liabilities decreased with higher discount rates (i.e. gilt yields, see Figure 6).

6.2 LASH Risk and the Liquidity Crisis

We argue that pre-existing LASH risk amplified the initial rise in interest rates following the Mini-Budget. LASH risk was not the fundamental trigger of the episode; rather, it propagated the shock by generating margin calls, forcing gilt sales to raise liquidity, and thereby putting additional upward pressure on yields. We proceed in three steps. We first show that, as expected, institutions with higher ex-ante LASH risk indeed faced more margin calls. Second, we show that institutions with higher LASH risk sold larger quantities of bonds. Third, we show that the sales induced by LASH risk seem to have caused higher interest rates.

To analyze the link between LASH risk, the liquidity demands and bond trading during the 2022 UK bond market crisis, we first divide the non-banks in our sample into four quartiles based on their pre-crisis LASH exposures, calculated from both their repo and swap positions. We measure the institution-specific LASH exposure on August 30, hence well in advance of the onset of the crisis and before the election of Liz Truss as Prime Minister. Our main sample includes all non-banks, and not just pension and LDI funds. The choice of sample is natural—other non-banks such as hedge funds are not endowed with long-term liabilities, and do not have incentives to take on LASH risk. These institutions serve as natural "control" observations. However, as we discuss, the results in this section remain robust even when focusing exclusively on pension funds.

Figure 7 CHANGE IN REPO MARGIN CALLS BY PRE-CRISIS LASH EXPOSURE



NOTE. Aggregate estimated changes in the value of repo collateral posted by UK non-bank financial institutions in £bn during the 2022 UK bond market crisis, by quartile of their pre-crisis LASH risk: Quartile I captures the non-banks with the lowest pre-crisis LASH exposures, while Quartile IV captures those with the highest pre-crisis LASH exposures. Source: Sterling Money Market data collection.

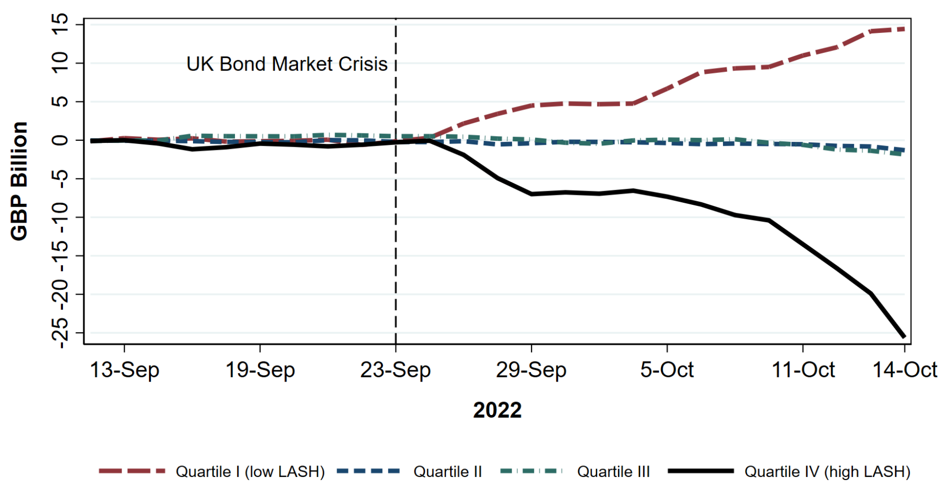
LASH risk and margin calls. First, Figure 7 shows that institutions with greater ex-ante LASH risk, indeed had greater liquidity needs due to their margin calls. We plot the cumulative change in repo collateral as a proxy for margin calls in the repo market, analyzed separately for each quartile of the ex ante LASH risk distribution.[17] A more negative number indicates greater margin calls. The plot goes from the start to the end of the liquidity crisis. Funds with the highest LASH risk faced the largest margin calls. This group mainly consists of pension and LDI funds, who had large net exposures in term repo borrowing (see Internet Appendix Figures II.1 & II.2). Consistent with this notion, we observe a similar pattern when plotting the same graph for pension funds only, as shown in Internet Appendix Figure II.12. As such, funds who were hedging solvency to a greater extent, indeed had greater liquidity needs as rates rose. The figure also shows that in aggregate repo margin calls increased—though disproportionately driven by high LASH risk funds.

LASH risk and bond sales. Second, we show that funds with higher ex ante LASH risk sold more bonds—in order to raise liquid assets and meet their margin calls. Figure 8 shows that the institutions with the highest pre-crisis LASH exposure (Quartile IV) sold many more government bonds compared to the other three groups. In total, this group sold

[17] This proxy for repo margin calls is exactly correct if haircuts do not change and there are no bilateral agreements to avert the margin call.

more than £25bn during the crisis, while the group with the lowest LASH risk (Quartile I), in fact, made net purchases of around £15bn worth of bonds. Before the crisis, the net volumes are very similar for all four groups. We again observe a similar pattern when plotting the same graph for pension and LDI funds only (Internet Appendix Figure II.13), the net sales of the pension fund sector were concentrated in the group of funds with the largest pre-crisis LASH exposures (Quartile IV). Again, we do not observe any differential pre-crisis trends.

Figure 8 Cumulative Gilt Trading by Pre-crisis LASH Exposure



NOTE. Total net bond trading volumes of UK non-banks, by quartile of their pre-crisis LASH risk: Quartile I captures the non-banks with the lowest pre-crisis LASH exposures, while Quartile IV captures those with the highest pre-crisis LASH exposures.

To quantify the relationship between pre-crisis LASH risk and gilt selling pressure, we estimate:

$$Vol_{j,t} = \alpha + \alpha_{s,t} + \beta_1 LASH_{j,0} + \varepsilon_{j,t}, \tag{11}$$

where $Vol_{j,t}$ is either (i) institution j's net gilt trading volume on day t (positive for net purchases, negative for net sales), or (ii) its gilt sell volume on day t (defined as the value of sales, which is nonnegative). $LASH_{j,0}$ is the institution's pre-crisis exposure measured on August 30 and standardized to unit cross-sectional variance. We calculate a "combined" LASH measure, which captures the LASH risk from both repo and IRS exposures, but we also run separate regressions for these two individual LASH risk components. We define the crisis period as the sixteen trading days between September 23 and October 14 (see Pinter, 2023). Again, net and sell volumes are transformed using the inverse hyperbolic sine transformation to give the regression coefficient β_1 an approximate percent change interpretation even if net volumes are negative. We include sector×day fixed effects, $\alpha_{s,t}$, so that identification is driven by within-sector differences across institutions.

Table 3 LASH RISK AND GILT TRADING VOLUMES

	(1)	(2)	(3)	(4)
	Net Volume		Sell Volume	
LASH combined	-0.21***		0.15***	
	(0.04)		(0.02)	
LASH Repo		-0.16***		0.12***
		(0.04)		(0.02)
LASH IRS		-0.13*		0.08***
		(0.05)		(0.02)
Observations	8875	8875	8875	8875
R squared	0.035	0.035	0.046	0.046
Sector-Day FE	yes	yes	yes	yes

NOTE. For each non-bank financial institution, as defined in equation 7 in Section 3.2, "LASH" is measured as the potential liquidity needs following a 100bps shift in gilt yields, either for repo and IRS exposures combined, or separately for both instruments. The dependent variable is the institution's daily gilt net trading volume on day t in Columns (1) and (2), and the institution's sell volumes on day t in Columns (3) and (4). The dependent variables are transformed using the Inverse Hyperbolic Sine method. The LASH variable is standardized. Double-clustered standard errors on the day and sector level are reported in parentheses. We include sector-day fixed effects. *** p<0.01, ** p<0.05, * p<0.1. Coefficients corresponding to the constant, control variables and fixed effects not reported.

The results are shown in Table 3. Consistent with Figure 8, we find that institutions with larger pre-crisis LASH exposures sold substantially higher quantities of gilts during the UK bond market crisis: a one standard deviation increase in pre-crisis LASH risk is associated with more than 15% higher daily sell volumes during the crisis period (Column 3). Importantly, this effect is robust to the inclusion of sector×day fixed effects, hence not driven by time-varying sector characteristics. Furthermore, the effect is economically and statistically more significant for the LASH risk from repo exposures, consistent with the larger magnitude of overall LASH risk in the repo market. As a robustness check, we also conduct our analysis exclusively for the pension and LDI fund sector in Internet Appendix Table II.5. Consistent with our baseline results, a one standard deviation increase in LASH risk is associated with a 10% increase in pension fund daily sell volumes.

LASH risk and rising rates. The third factor characterizing the liquidity crisis was a continued rise in rates after the initial shock of the Mini-Budget. We show that LASH risk contributed to the subsequent rise in rates. To isolate the impact of LASH risk on non-bank trading and, in turn, on yield movements, we follow Czech et al. (2023) and construct a measure of *LASH-induced trading (LASH-IT)*. Specifically, we calculate each institution's LASH-induced trading in bond b assuming that each institution proportionally scales up or down its holdings in response to liquidity demands. Due to the lack of complete information on bond holdings of individual institutions, we approximate the weight of bond b in institution j's portfolio, $w_{j,b}$, by measuring the weight of the given bond in institution's j pre-crisis repo collateral portfolio. LASH-induced trading (LASH-IT) in bond b is then defined as:

$$LASH\text{-}IT_b = \frac{\Sigma_j LASH_{j,0} \times w_{j,b,0}}{Amount\ Outstanding_{b,0}} \tag{12}$$

where $LASH_{j,0}$ is the estimated pre-crisis LASH exposure of institution j, and $w_{j,b,0}$ is the weight of bond b in institution's j pre-crisis repo collateral portfolio, and *Amount Outstanding*$_{b,0}$ is the bond's amount outstanding before the crisis. We then employ the following regression specification to measure the impact of LASH-induced trading on gilt yields during the crisis:

$$\Delta Yield_{b,t} = \alpha + \alpha_{m,t} + \alpha_{g,t} + \beta_1 LASH\text{-}IT_b + \Gamma X_{b,t} + \varepsilon_{b,t} \tag{13}$$

where $\Delta Yield_{b,t}$ is the daily change in yields. Again, we define the crisis period as the sixteen trading days between September 23 to October 14. We include maturity-bucket×day fixed effects ($\alpha_{m,t}$) and type×day fixed effects ($\alpha_{g,t}$; nominal versus index-linked), so identification comes from differences across bonds within the same maturity bucket and gilt type on a given day. $X_{b,t}$ includes additional bond-level controls, including the bond's time-to-maturity, coupon, and hourly trade costs.

Table 4 presents the results. The effect is statistically and economically highly significant. In the most conservative specification with maturity bucket×day and type gilt×day fixed effects (Column 4), a one standard deviation increase in LASH-IT is associated with a 4.1bps daily increase in gilt yields.

6.3 Sources of Illiquidity

During the liquidity crisis, pension fund solvency improved (Figure 6). Why, then, could funds not use that improved solvency to raise liquidity and avert fire sales? This subsection highlights three frictions that can make an institution illiquid even as its net worth rises: (i) solvency gains largely reflected a revaluation of liabilities rather than an increase in pledgeable resources; (ii) limited liquidity management infrastructure and market access at

Table 4 Impact of LASH-IT on Gilt Yields

	(1)	(2)	(3)	(4)
	$\Delta Yield_{b,t}$			
LASH-IT	8.76***	8.85***	3.97**	4.11***
	(1.08)	(1.09)	(1.67)	(1.55)
Observations	1253	1253	1253	1253
R squared	0.264	0.324	0.617	0.649
Controls	yes	yes	yes	yes
Day FE	yes	-	-	-
Day × Type Gilt FE	no	no	yes	yes
Day × Maturity Bucket FE	no	yes	no	yes

Note. As the dependent variable, we measure the daily change in yields for each bond. The independent variable is the bond's LASH-induced trading ("LASH-IT") in bond b on day t as defined in equation 12. The dependent variable is transformed using the Inverse Hyperbolic Sine method. The independent variable is standardized. We include the bond's time-to-maturity, coupon, and hourly trade costs as controls. Standard errors clustered on the bond level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Coefficients corresponding to the constant and fixed effects not reported.

some funds; and (iii) constraints on the supply of secured funding during stress.

Improvements in solvency came from falling liabilities. Securing liquidity against a decline in liabilities is difficult. A declining value of liabilities cannot be pledged as collateral and used for secured lending. In principle, funds might be able to access liquidity via unsecured lending. However, in practice, unsecured lending is uncommon in the UK pension fund sector. In particular, pension funds do not seem to borrow unsecured via credit lines. Stress test data from year-end 2021, i.e. the last period before the crisis, reveals no UK pension funds with available credit commitments from the listed exposures of major UK banks. Instead, the primary source of liquidity for UK pension funds is collateralized borrowing in the repo market.

Limited liquidity management infrastructure. Many funds had limited operational capacity to raise liquidity quickly. For example, only around half of institutions active in the swap market also accessed the repo market prior to the crisis (Internet Appendix Figure II.14). Even when a fund holds eligible collateral, arranging secured borrowing at short notice is difficult without pre-existing repo relationships, documentation, and operational processes.

The cross-sectional pattern of fund-level sales suggests that frictions in liquidity management were partly responsible for bond sales. We therefore use two pre-crisis proxies for limited liquidity management capacity. First, we identify institutions that did not access the repo market in the quarter prior to the crisis (despite being active in swaps), which captures limited secured funding access at short notice. Second, within the LDI sector, we distinguish between pooled and segregated LDI structures. As discussed in Section 2.4, pooled LDI funds aggregate capital from multiple pension schemes, and meeting large margin calls can require liquidity to be transferred from multiple ultimate owners to the pooled vehicle. In practice, these transfers can be slow due to institutional frictions and low-frequency rebalancing at some pension schemes (Breeden, 2022). By contrast, segregated mandates have a single owner, which can facilitate faster liquidity provision to the LDI vehicle.[18]

To test these channels, we augment the baseline specification in equation (11) in two ways. First, we add a pre-crisis indicator ("Swap Only") for institutions that were active in the swap market but not in the repo market in the quarter prior to the crisis, capturing limited secured funding access. We then interact the indicator variable with $LASH_{j,0}$, while maintaining the same fixed effects structure as in the baseline crisis regressions. Second, for LDI funds, we allow the sensitivity of sales to pre-crisis LASH exposure to differ by pooled versus segregated structures by interacting $LASH_{j,0}$ with pooled/segregated indicator variables.

Table 5 shows that our proxies for liquidity management frictions predict bond sales during the crisis. Institutions that were active in swaps prior to the crisis, but not in repo, sell approximately twice as much per unit of LASH risk, compared to other investors who also have access to the repo market (Column 2). Within the LDI sector, pooled structures exhibit a markedly stronger relationship between pre-crisis LASH exposure and selling: the estimated sensitivity of sell volumes to $LASH_{j,0}$ is substantially larger for pooled LDI funds than for other non-banks (Column 3), while the analogous interaction for segregated mandates is not statistically significant (Column 4). It is worth noting that pooled LDI funds' sales account for only around 15% of the total bond sales by pension funds and LDI funds during the crisis (Internet Appendix Figure II.11), so pooled funds cannot alone account for the bond sales.

Constraints on supply of liquidity. The UK bond market experienced a market-wide increase in the demand for liquidity. The increase in aggregate demand for liquidity may have exhausted supply. In particular, there may have been limits to the repo market's ability to supply the required liquidity. Overnight repo spreads spiked by more than 30bps during the crisis (Internet Appendix Figure II.14).

[18] At the end of 2021, approximately £200bn of the £1.4tn in UK LDI assets were invested in multi-institution pooled funds (Breeden, 2022).

Cross-sectional sales patterns also point to supply constraints. Repo relationships are "sticky": newly formed counterparty pairs account for only around 4% of repo trades (Internet Appendix Figure II.15). This stickiness implies that, in stress, an institution's effective funding conditions depend heavily on the dealers it already relies on. We therefore construct a pre-crisis exposure measure based on dealer-specific repo spreads. Dealers charging higher spreads prior to the crisis plausibly faced a higher marginal cost of providing balance sheet-intensive repo lending, so funds reliant on these "high-spread" dealers may have been more exposed to constrained liquidity supply during the episode.

Using our measure, we revisit the regression model in equation (11). We add another indicator variable that measures whether a given non-bank obtained the majority (more than 50%) of its funding from "high-spread" dealers—that, on average, charge their clients more than the market median for term repo borrowing—in the quarter prior to the crisis. Using this measure, we find that the sensitivity of sell volumes to pre-crisis LASH risk is about twice as large for non-banks with higher pre-crisis exposure to high-spread dealer banks (Column 5). We infer that constraints on the supply of liquidity in the repo market was an important reason for bond sales.

Overall, three forces can explain why pension funds struggled to raise liquidity despite improving solvency: the solvency gains were largely non-pledgeable (liability revaluations), some funds faced operational and institutional frictions in mobilizing liquidity, and secured funding supply tightened during stress. These mechanisms also highlight why the sectoral location of LASH risk matters. Institutions with direct access to central bank liquidity facilities, or with established secured funding infrastructure, may be better able to absorb margin calls without disruptive asset sales. For non-banks, which typically rely on dealer-intermediated repo funding and face greater operational constraints, LASH risk is more likely to translate into fire sales and market stress.

6.4 Bond Level Characteristics

We close the paper by asking whether sales were concentrated in bonds with particular characteristics. We run the following regression at the institution-bond-day level:

$$Sell\ Vol_{j,b,t} = \alpha + \alpha_{s,t} + \alpha_{b,t} + \beta_1 LASH_{j,b,0} + \beta_2 \left(LASH_{j,b,0} \times Bond\ Characteristics_b\right) + \varepsilon_{j,b,t} \tag{14}$$

where $Sell\ Vol_{j,b,t}$ measures the sell volume of institution j in bond b at time t. *Bond Characteristics* includes: i) three duration buckets (low, medium, high), ii) two groups

Table 5 LASH RISK AND SOURCES OF ILLIQUIDITY

	(1)	(2)	(3)	(4)	(5)	(6)
			Sell Volume			
LASH	0.15***	0.14***	0.14***	0.20***	0.14***	0.12**
	(0.02)	(0.01)	(0.02)	(0.05)	(0.01)	(0.04)
LASH × Swap-only		0.15***				0.17*
		(0.04)				(0.07)
LASH × Pooled LDI Fund			0.93***			0.95***
			(0.02)			(0.09)
LASH × Segregated LDI Fund				-0.08		0.00
				(0.06)		(0.05)
LASH × High Spread Exposure					0.14***	0.16*
					(0.03)	(0.08)
Observations	8875	8875	8875	8875	8875	8875
R squared	0.046	0.047	0.050	0.047	0.047	0.051
Sector-Day FE	yes	yes	yes	yes	yes	yes

NOTE. For each non-bank financial institution, LASH is measured as the potential liquidity needs following a 100bps shift in gilt yields for repo and IRS exposures combined. The dependent variable is the institution's daily sell volume on day t. Segregated LDI Fund and Pooled LDI Fund indicate segregated and pooled LDI funds, respectively. Swap-only indicates institutions that have no activity in the repo market in the quarter prior to the crisis. High Spread Exposure indicates whether the majority (more than 50%) of repo borrowing of a given institution is with high-spread dealers (that charge more than the market median on average) in the quarter prior to the crisis. The dependent variable is transformed using the Inverse Hyperbolic Sine method. The LASH variable is standardized. Double-clustered standard errors on the day and sector level are reported in parentheses. We include sector-day fixed effects. *** p<0.01, ** p<0.05, * p<0.1. Coefficients corresponding to the constant, control variables and fixed effects not reported.

measuring the frequency of the bonds's usage as repo collateral (as measured by the total pre-crisis repo borrowing amount for each bond across all non-banks), and iii) an indicator variable for index-linked bonds. $LASH_{j,0}$ is defined as in equation (11). We include both sector×day and bond×day fixed effects and use standard errors clustered on the day, sector and maturity-bucket level.

The results are presented in Table 6. Consistent with our baseline results, we find that higher pre-crisis LASH risk predicts bond selling pressure, even when controlling for sector×day and bond×day fixed effects. We find that the effect is particularly pronounced for high-duration bonds, bonds that are frequently used as repo collateral and index-linked bonds. For example, a one standard deviation increase in LASH is associated with 6% higher daily sell volumes in index-linked gilts (relative to 4% higher sales in nominal bonds).

Table 6 LASH Risk and Bond-level Liquidation Choices

	(1)	(2)	(3)	(4)
	Sell Volume			
LASH	0.05***	0.04***	0.04***	0.04***
	(0.00)	(0.00)	(0.00)	(0.00)
LASH × Frequent Collateral Use		0.01*		
		(0.00)		
LASH × Low Duration			0.01	
			(0.01)	
LASH × High Duration			0.01*	
			(0.00)	
LASH × Inflation-linked				0.02**
				(0.01)
Observations	42481	42382	41667	42481
R squared	0.115	0.115	0.114	0.115
Bond-Day FE	yes	yes	yes	yes
Sector-Day FE	yes	yes	yes	yes

Note. For each non-bank financial institution, as defined in equation 7 in Section 3.2, "LASH" is measured as the potential liquidity needs following a 100bps shift in gilt yields, for repo and IRS exposures combined. The dependent variable is the institution's daily gilt sell volume in bond b on day t. "Frequent Collateral Use" indicates the frequent use of bond b as repo collateral, i.e. the top 50% of bonds based on their use as repo collateral. "Duration" indicates the duration bucket of bond b (long, medium, short). "Inflation-linked" indicate index-linked gilts. The dependent variable is transformed using the Inverse Hyperbolic Sine method. The LASH variable is standardized. Clustered standard errors on the day, sector and maturity-bucket level are reported in parentheses. We include sector-day fixed effects. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Coefficients corresponding to the constant, control variables and fixed effects not reported.

7 Conclusion

In this paper, we introduce a framework to understand and measure *Liquidity After Solvency Hedging (LASH) risk*: liquidity needs that arise because institutions hedge solvency risk using instruments whose value can fall when solvency improves. We focus on non-banks—such as pension funds—with long-duration liabilities and shorter-duration assets, for whom declines in interest rates tend to reduce solvency and strengthen the incentives to hedge, potentially increasing LASH risk. While our analysis centers on interest rate hedging, the same logic applies to other asset classes, and we discuss related episodes across markets and jurisdictions.

We make three empirical contributions. First, we measure LASH risk for the near-universe of UK non-banks' sterling interest rate exposures—via interest rate swaps and repo—from 2019 onward. LASH risk is large: at its peak, a 100bps rise in rates would generate liquidity needs that nearly exhaust the combined cash holdings of the pension fund and insurance sectors. Yet pension funds are only partially hedged against rate risk, so solvency still improves when rates rise. Second, we show that low rates increase LASH risk. In the aggregate time series, LASH risk is elevated when yields are low. In the cross-section, institutions with larger solvency exposure to rate declines—captured by proxies for the balance sheet duration mismatch—raise LASH risk more when rates fall. Third, we show that LASH risk can amplify rate shocks into liquidity crises even as solvency improves: during the 2022 UK bond market turmoil, pre-crisis LASH exposure strongly predicts crisis-period gilt sales and is associated with larger yield increases.

The implications of LASH risk are different from some other forms of liquidity risk. LASH risk arises from 'responsible' institutions trying to hedge solvency risks, and the risk materializes precisely when solvency improves. LASH risk is thus different from other forms of liquidity risk that materialize when solvency deteriorates. Therefore, mitigating the adverse effects of LASH risk ex post—through measures such as liquidity support during a crisis—may not encourage solvency risk ex ante. As such, the policy trade-offs from intervening during a crisis may be different from conventional liquidity crises. We leave a full investigation of these ideas to future work. Likewise, we leave the analysis of LASH risk and its implications in other market segments (e.g., foreign exchange or inflation) for future research.

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Appendix

A Details on LASH Risk Episodes

This section discusses a series of episodes in which LASH risk led to liquidity crises of various kinds. The core pattern was the same in each case. Institutions hedged against a solvency risk from a change in an asset price. When the asset price moved in their favor—raising solvency and lowering the value of the hedge—institutions faced margin calls. The result was liquidity stress, even as solvency improved.

A.1 Dash for Cash (2020)

Non-US financial institutions that hold dollar-denominated assets typically hedge the associated currency exposure with foreign exchange derivatives, since their liabilities are mostly denominated in the domestic currency. During periods of global financial stress, the dollar tends to appreciate, ceteris paribus increasing the value of their dollar-denominated asset portfolios. At the same time, however, the dollar appreciation generates liquidity pressures through variation margin calls on FX hedging positions, which must be met in cash. The immediacy and large scale of these margin calls can force investors to raise liquidity through asset sales.

Czech et al. (2023) use regulatory data on UK insurers and pension funds (ICPFs) to provide direct evidence for this mechanism. The sharp dollar appreciation during the March 2020 Dash for Cash triggered sizable margin calls on FX hedges, inducing ICPFs to raise liquidity through forced sales of UK government bonds. The resulting selling pressure significantly contributed to the pronounced yield spike in the gilt market during this episode. The authors also document a similar pattern in other advanced economies such as Canada, the euro area, and Japan.

A.2 US and European Life Insurers and Pension Funds (2021–3)

To recap the basic economics, recall that life insurers and pension funds hold long-duration liabilities—promises to pay beneficiaries decades into the future. The present value of these liabilities is highly sensitive to interest rates: when rates fall, the discount factor increases, making future payments more expensive in today's terms. A 100bps rate decline might increase liability valuations by 15-20% for typical life insurance portfolios. To protect their balance sheets against falling rates, insurers and pension funds constructed duration-matched hedges using: interest rate swaps (receiving fixed, paying floating), long-dated government bonds (gilts in the UK case), and various other derivatives.

Aquilina et al. (2025) point out that when global rates rose sharply during 2021-3, insurers faced mark-to-market losses on hedges. As rates increased, the value of their rate hedges (long duration positions) fell sharply. The result was margin calls: derivatives contracts required cash collateral to cover these losses. Unlike the liabilities (which improved in present value terms), these margin requirements were cash-settled and immediate. Overall, economic solvency improved: rising rates reduced the present value of long-dated insurance liabilities, strengthening the fundamental balance sheet. Nevertheless, there were liquidity problems. Consistent with this evidence, Jansen et al. (2023) use regulatory data on Dutch pension funds to show that these funds hedge extensively with interest rate swaps, which exposed them to large margin calls in the recent rate hiking cycle. These margin calls were met through sales of domestic government bonds, despite the funds' improved solvency.

A.3 Metallgesellschaft (1993)

The German energy conglomerate Metallgesellschaft AG offered customers long-term fixed-price contracts (5-10 years) to supply heating oil and gasoline. These contracts guaranteed prices at around at \$3-5 per barrel above current oil spot prices—allowing customers to "lock in" prices at a premium, but creating risks for Metallgesellschaft if the oil price were to rise. By late 1993, they had sold forward approximately 150-180 million barrels of petroleum products, creating enormous exposure to oil price increases. To hedge this exposure, Metallgesellschaft employed a "stack and roll" strategy, as discussed in Culp and Miller (1994).

Instead of buying long-dated futures matching the delivery dates (a "strip hedge"), they bought a large "stack" of short-dated futures (primarily near-month contracts). As contracts expired, they would "roll" them forward into the next month. The strategy assumed a one-to-one hedge ratio—hedging each barrel of long-term delivery with one barrel of short-term futures. If oil markets were in backwardation (near-term prices higher than long-term), then there would be profits to offset the premium offered to customers.

In late 1993, oil prices collapsed, falling from $20/barrel to $15/barrel. The value of these futures fell enormously, meaning margin calls, in cash, of $900 million. At the same time, the contracts offered to Metallgesellschaft's customers became more valuable, since Metallgesellschaft could buy oil more cheaply while charging their customers the same price. As such, there was a liquidity crisis despite better solvency. In December 1993, Metallgesellschaft unwound their futures positions at a final loss of around $1.5 billion. While the company did not fail, it required a $1.9 billion rescue package orchestrated by a consortium of German and international banks.

A.4 Ashanti Goldfields (1999)

Ashanti Goldfields was Ghana's largest gold producer and one of Africa's top mining companies. Like many commodity producers, Ashanti used derivatives extensively to hedge against the risk that gold prices would fall. By mid-1999, Ashanti had hedged approximately 10 million ounces of future gold production through a combination of forwards, call options on gold, and more complex hedging strategies. This created a massive short position in gold—if gold prices were to decline, Ashanti would gain, to offset the losses that they would otherwise face from a declining gold price.

On September 26, 1999, 15 European central banks announced the Washington Agreement on Gold, limiting their gold sales and lending. Gold prices surged by around 25% in days (from $255/oz to $325/oz), the largest spike in decades.

As a result, Ashanti faced liquidity stress despite its improved solvency. Higher gold prices meant higher revenues from physical gold sales. Therefore Ashanti's mines became more profitable, and revenue increased substantially. However the value of the hedge collapsed.

Ashanti's short derivatives positions lost enormous value (around $570 million mark-to-market loss on positions covering 10+ million ounces). Counterparties issued margin calls demanding cash collateral. Ashanti faced $270 million in margin calls that had to be paid within days. However the company did not have sufficient collateral—their main asset was physical gold, which was "in the ground". Overall, as Adam and Fernando (2006) point out, Ashanti was arguably solvent—rising gold prices meant their reserves were worth more, and future operating cash flows would be higher. However, Ashanti was illiquid—they couldn't meet immediate margin calls despite long-run solvency.

Ashanti narrowly avoided bankruptcy through emergency refinancing. Banks agreed to freeze margin calls temporarily. The company drastically reduced hedging positions (at enormous cost). Ashanti was eventually acquired by AngloGold in 2004.

A.5 Cotton Market Turmoil (2008)

As background, cotton merchants operate by purchasing cotton from growers before harvest using forward contracts—agreeing to buy the crop at a predetermined price months in advance. This agreement creates inventory risk: if cotton prices fall between the forward purchase and eventual sale, merchants suffer losses on their physical holdings. The response is a hedging strategy. To protect against price declines, merchants take positions in cotton futures markets (agreeing to sell cotton at fixed future prices). This hedge acts as insurance: if cotton prices fall, losses on physical inventory are offset by gains on the short futures position.

When cotton prices unexpectedly increased, in March 2008, the hedging strategy backfired (Carter and Janzen, 2008). As cotton futures prices rose, merchants' short hedge positions moved against them, triggering margin calls requiring immediate cash payments Meanwhile, their physical cotton inventory increased in value, but this wealth was illiquid—tied up in as-yet-undelivered cotton that could not be converted to cash. The result was a liquidity crisis and cascading failures. Unable to meet margin calls despite improving solvency, multiple cotton merchants failed, including some of the biggest players in the market (e.g., Paul Reinhart Inc, Weil Brothers).

B Additional Theoretical Results

B.1 Proof of Proposition 1

Proof preliminaries To start, we reformulate the problem and define some notation. Under our described process for the interest rate, the asset prices in period $t+1$ follow:

$$q^l_{t+1}(\varepsilon_{t+1}) = \frac{\varepsilon_{t+1} + R_t^{-1}}{1 - \bar{R}^{-1}},$$

$$q^b_{t+1}(\varepsilon_{t+1}) = \frac{\varepsilon_{t+1} + R_t^{-1}}{1 - \delta\bar{R}^{-1}}.$$

The shock, ε_{t+1}, has support $\varepsilon_{t+1} \in (\varepsilon^l, \varepsilon^h)$ with ε^h positive and finite so the gross rate cannot fall to zero, and $\varepsilon^l \geq -R_t^{-1}$ with an upper bound that we will define below. Denote the cumulative density of the shock $F(\varepsilon)$, with corresponding p.d.f. $f(\varepsilon)$. The initial level of the R_t^{-1} can be treated as a primitive of the problem.

The proposition assumes a sufficiently high liquidity premium on the short-run asset. For simplicity, we set $\eta \to \infty$, so $a_t = 0$. To ease notation we occasionally drop function dependencies on ε_{t+1} and s_t. The problem can then be recast as simply choosing the optimal amount of hedging at time t (with b_t given):

$$\max_{s_t} \mathbb{E}_t \left[(1 + \kappa \mathbf{1}\left[w_{t+1} < 0\right]) \, w_{t+1} \right], \tag{B.1}$$

subject to:

$$w_{t+1}(\varepsilon_{t+1}, s_t) = b_t - l + q^b_{t+1}\delta b_t + s_t\varepsilon_{t+1} + \frac{c}{1-c}\min\left\{m_{t+1}, 0\right\} - q^l_{t+1} l,$$

$$m_{t+1}(\varepsilon_{t+1}, s_t) = b_t + s_t\varepsilon_{t+1} - l.$$

It is useful to define:

$$y(\varepsilon_{t+1}) = b_t - l + q^b_{t+1}\delta b_t - q^l_{t+1} l,$$

This represents the unhedged value of the fund. From assumption 1, the fund is solvent in period t in the sense that $y(0) > 0$ but $y(\varepsilon^h) < 0$. Given the definitions of q^b_{t+1} and q^l_{t+1}, it is straightforward to see that solvency condition requires $b_t > l$. We also have:

$$\frac{dy}{d\varepsilon_{t+1}} = \frac{\left(\delta - \delta\bar{R}^{-1}\right) b_t - \left(1 - \delta\bar{R}^{-1}\right) l}{\left(1 - \delta\bar{R}^{-1}\right)\left(1 - \bar{R}^{-1}\right)}.$$

This is negative so long as $\frac{b_t}{l} < \frac{\left(1-\delta\bar{R}^{-1}\right)}{\delta\left(1-\bar{R}^{-1}\right)}$, and this is required by the first part of assumption 1. This means the fund is not so wealthy that the gain on its medium-duration assets from lower rates offsets the duration mismatch from its longer-duration liabilities. A negative value for the derivative implies, absent hedging, that the fund loses out the more positive the shock and the lower the rate.

Given the function $y(\varepsilon_{t+1})$ is exogenous and linear, it is useful to parameterize it as:

$$y = y_0 + y_1\varepsilon_{t+1}, \tag{B.2}$$

where $y_0 \equiv y(0) > 0$ and $y_1 \equiv \frac{dy}{d\varepsilon_{t+1}} < 0$. At this point, it is worth noting that y_0 is decreasing in R_t^{-1} at rate y_1 and y_1 is invariant to R_t^{-1} as this will be used later.

The proposition states that the upside risk on the interest rate is sufficiently high. We now define the upper bound on ε^l which pins down how far interest rates could rise. We impose:

$$\varepsilon^l < \frac{b_t - l}{\left(\frac{y_0}{\varepsilon^h} + y_1\right)}. \tag{B.3}$$

As we shall see, this condition will ensure that if the fund hedges sufficiently to remove all risk of insolvency when rates fall, it will face a liquidity crisis if there is a sufficiently large rise in rates.

Hedging choices absent liquidity costs. Define s_t^{**} as a value of s_t that solves problem (B.1) when $c = 0$. Since $\mathbb{E}_t\left[\varepsilon_{t+1}\right] = 0$ this is is equivalent to:

$$s_t^{**} = \max_{s_t} \mathbb{E}_t\left[\mathbf{1}\left[y_0 + \left(s_t + y_1\right)\varepsilon_{t+1} < 0\right]\left(y_0 + \left(s_t + y_1\right)\varepsilon_{t+1}\right)\right].$$

Note the maximand is weakly negative with a maximum at zero. From the linearity of $y_0 + \left(s_t + y_1\right)\varepsilon_{t+1}$, the objective is maximized, for any s_t where both $y_0 + \left(s_t + y_1\right)\varepsilon_{t+1}^h \geq 0$

and $y_0 + (s_t + y_1)\,\varepsilon^l_{t+1} \geq 0$. Selecting

$$s_t^{**} = -y_1, \tag{B.4}$$

fully insures the fund against interest rate risk and hence guarantees the objective is at the maximum given $y_0 > 0$. However, there is a complete set of solutions given by $s_t^{**} \in [\underline{s}, \bar{s}]$ where

$$\underline{s} = -\left(\frac{y_0}{\varepsilon^h} + y_1\right) \leq |y_1|\,,$$
$$\bar{s} = -\left(\frac{y_0}{\varepsilon^l} + y_1\right) > |y_1|\,.$$

If $s_t^{**} = \underline{s}$, the fund does not remove all interest rate risk but hedges sufficiently to ensure its solvency in the worst-case scenario. If $s_t^{**} = \bar{s}$, the fund over-hedges so that its net worth is decreasing in the interest rate but not so much that at the highest possible value of the rate, the fund is insolvent.

Last, for any $s_t < \underline{s}$, the probability of insolvency is positive, and the fund's payoff can always be improved by increasing s_t towards $\underline{s}$. This implies that absent liquidity costs, $s_t < 0$ is not optimal either.

Hedging choices with liquidity costs. Define, s_t^* as a value of s_t that solves problem (B.1) when $c > 0$. Conjecture that there exists an s_t^* that is unique, positive and less than $\underline{s}$. We will first characterize s_t^* under this conjecture, proving points $(ii) - (iii)$ in the proposition. Then, we will confirm that the conjecture is correct, proving point (i).

For point (iii), note that:

$$m_{t+1} = b_t + s_t \varepsilon_{t+1} - l.$$

Hence, we can define a threshold realization $\varepsilon_0(s_t) = \frac{l - b_t}{s_t} < 0$, such that if the rate is sufficiently high ($\varepsilon_{t+1} < \varepsilon_0$) then $m_{t+1} < 0$ and the fund will be forced to sell assets. The threshold is increasing in s_t. The condition in equation (B.3) guarantees $\varepsilon_0(\underline{s}) > \varepsilon^l$. What is left to show is that $\varepsilon_0(s_t^*) > \varepsilon^l$ such that a sufficient rate rise will cause selling given the optimal choice s_t^*. If that is the case, for any positive s_t^* that is less than less than

$\underline{s}$, the firm will have net worth greater than y_0 if the realized shock is at the threshold $\varepsilon_0(s_t^*)$. Liquidation costs are infinitesimal at the threshold and the fund imperfectly hedged so benefits from higher rates.

As $s_t < \underline{s}$, there is also a threshold realization,

$$\varepsilon_1(s_t) = \frac{y_0}{-(y_1 + s_t)},$$

such that if the rate is sufficiently low ($\varepsilon_{t+1} > \varepsilon_1(s_t)$) then $w_{t+1} < 0$. Note that $\varepsilon_1(s_t) > 0$ as $y_0 > 0$ and $y_1 + s_t$ is negative for $s_t \leq \underline{s}$.

At this point, it is useful to distinguish between two cases. *Case (i)*: $w_{t+1}(\varepsilon^l, \underline{s}) > 0$; *Case (ii)*: $w_{t+1}(\varepsilon^l, \underline{s}) < 0$. In *Case (i)*, if the fund hedges sufficiently to avoid insolvency when rates fall, the losses from illiquidity when rates rise are never sufficient for it to also become insolvent for very large interest rate rises. In *Case (ii)*, the liquidation costs on the hedge can be sufficiently large that in the case of high rates such that fund is insolvent.

We will first with complete the proof assuming *Case (i)* holds, and then show that *Case (ii)* is ruled out by assumption 1. In *Case (i)*, problem (B.1) can be expressed as:

$$\max_{0<s_t<\underline{s}} \mathbb{E}_t \left[\kappa \int_{\varepsilon_1(s_t)}^{\varepsilon^h} (y_0 + (s_t + y_1)\,\varepsilon_{t+1})\, dF(\varepsilon) + \frac{c}{1-c} \int_{\varepsilon^l}^{\varepsilon_0(s_t)} (b_t + s_t\varepsilon_{t+1} - l)\, dF(\varepsilon) \right].$$

Noting the first integrand above is zero evaluated at $\varepsilon_1(s_t)$, and the second integrand is zero evaluated at $\varepsilon_0(s_t)$, the relevant first order condition is:

$$\kappa \int_{\varepsilon_1(s_t^*)}^{\varepsilon^h} \varepsilon_{t+1} dF(\varepsilon) + \frac{c}{1-c} \int_{\varepsilon^l}^{\varepsilon_0(s_t^*)} \varepsilon_{t+1} dF(\varepsilon) = 0. \tag{B.5}$$

The first term in equation (B.5) is strictly positive for $s_t < \underline{s}$ and is the marginal benefit of an additional unit of hedging in terms of reducing the risk of insolvency. The second term is weakly negative for $s_t < \underline{s}$, strictly if $\varepsilon_0(s_t^*) > \varepsilon^l$, and is the marginal cost of an additional unit hedging in terms of extra liquidation costs.

The corresponding second order condition is (noting $\varepsilon_0 < 0$, $\varepsilon_1 > 0$ and $y_1 + s_t^* < 0$):

$$\kappa \frac{\varepsilon_1^2}{(y_1 + s_t^*)} f(\varepsilon_1) - \frac{c}{1-c} \varepsilon_0^2 f(\varepsilon_0) < 0,$$

hence s_t^* corresponds to an interior maximum where the probability $\varepsilon_0(s_t^*) > \varepsilon^l$ of insolvency is positive. Now imagine that $\varepsilon_0(s_t^*) < \varepsilon^l < 0$, then the fund could increase s_t and reduce the probability of insolvency with no corresponding costs of illiquidity. Hence, we must have that s_t^* is sufficiently large $\varepsilon_0(s_t^*) > \varepsilon^l$. This proves point (iii).

We now prove point (ii) under *Case (i)*. Note that R_t^{-1} enters first order condition (B.5) solely through the definition of y_0 in ε_1. Recalling $\frac{dy_0}{dR_t^{-1}} = y_1$, and applying the implicit function theorem, we obtain:

$$\frac{ds_t^*}{dR_{t-1}^{-1}} = \underbrace{\left(\frac{1}{\frac{c}{1-c}\varepsilon_0^2 f(\varepsilon_0) - \kappa \frac{\varepsilon_1^2}{(y_1+s_t^*)} f(\varepsilon_1)} \right)}_{>0} \underbrace{\frac{\kappa \varepsilon_1 y_1}{(y_1 + s_t^*)} f(\varepsilon_1)}_{>0}.$$

Hence, the equilibrium level of hedging is decreasing in the initial level of the interest rate. This proves point (ii).

We now confirm that the conjectures regarding the equilibrium level of hedging s_t^* are true. Consider the bounds $0 < s_t^* < \underline{s}$. Start with the conjecture $s_t^* > 0$. Imagine, instead that s_t^* was mildly negative such that there was no liquidity risk from the swap position. This is equivalent to the $c = 0$ case, and a marginal increase in the fund's swap position would add

$$\kappa \int_{\varepsilon_1(s_t)}^{\varepsilon^h} \varepsilon_{t+1} dF(\varepsilon) > 0$$

to the expected payoff. Expanding a negative swap position to the point where liquidity risk emerges only introduces an additional benefit of increasing s_t through reducing liquidation costs if rates rise. The same argument holds at $s_t = 0$. There is no liquidity risk at $s_t = 0$, so raising s_t unambiguously raises the expected payoff.

Now consider the conjecture $s_t^* < \underline{s}$. At the point $s_t^* = \underline{s}$, solvency risk is nil and s_t comes with a marginal cost of illiquidity of $\frac{c}{1-c} \int_{\varepsilon^l}^{\varepsilon_0(\bar{s})} (-\varepsilon_{t+1}) dF(\varepsilon)$. Further increases in s_t from $\bar{s}$ would raise $\varepsilon_0(\bar{s})$ and hence liquidity costs further without any benefit in terms of reduced insolvency. Now a marginal reduction in s_t from $\underline{s}$ generates a cost of insolvency equal to $\kappa\varepsilon^h f(\varepsilon^h)$. However, as the probability density was arbitrarily small at the bounds this increase insolvency less than the marginal cost of illiquidity. Hence, $s_t^* = \underline{s}$ is not optimal.

Last consider the conjectured existence and uniqueness of s_t^*, note that first order condition can be expressed as:

$$\kappa \int_{\varepsilon_1(s_t^*)}^{\varepsilon^h} \varepsilon_{r,t+1} dF(\varepsilon) = \frac{c}{1-c} \int_{\varepsilon^l}^{\varepsilon_0(s_t^*)} (-\varepsilon_{r,t+1}) dF(\varepsilon).$$

For all $0 < s_t < \underline{s}$, the left hand side is positive and decreasing in s_t and from the assumptions on $F(\varepsilon)$ the left hand converges smoothly to 0 as $s_t \to \underline{s}$. For the right hand side, first note $\varepsilon_0(s_t)$ is increasing in s_t. For sufficiently low s_t, $\varepsilon_{r,0}(s_t) < \varepsilon^l$ then the right hand is zero and unaffected by a change in s_t. We know $\varepsilon_{r,0}(\underline{s}) > \varepsilon^l$, hence, for sufficiently large s_t, we will have $\varepsilon_{r,0}(s_t) > \varepsilon^l$ and the right hand side will be positive. Since, in the interval $s_t \in (0, \underline{s})$, the left hand side starts positive, is decreasing and tends to zero and the right hand side starts at zero, is weakly increasing and in positive at the upper end of the interval there exists a single crossing.

We now turn to ruling out *Case (ii)*. If $w_{t+1}(\varepsilon^l, \underline{s}) < 0$, there exists a potential third threshold $\varepsilon_2(s_t) < \varepsilon_0(s_t)$ whereby $y_0 + \left((1 + \frac{c}{1-c})s_t + y_1\right)\varepsilon_2(s_t) + \frac{c}{1-c}(b_t - l) = 0$ and $w_{t+1} < 0$ if $\varepsilon_{t+1} < \varepsilon_2(s_t)$. Now,

$$\varepsilon_2(s_t) = -\frac{\frac{c}{1-c}(b_t - l) + y_0}{\left((1 + \frac{c}{1-c})s_t + y_1\right)},$$

for this region to exist $s_t > \frac{-y_1}{(1+\frac{c}{1-c})} = -(1-c)y_1$. We also have $\underline{s} = -\left(\frac{y_0}{\varepsilon^h} + y_1\right)$. If $-(1-c)y_1\varepsilon^h > -\left(y_0 + y_1\varepsilon^h\right)$ this region cannot exist. This condition is satisfied by assumption 1.

B.2 Numerical Results with Model

Here we illustrate numerically that for a reasonable parameterization, as interest rates fall LASH risk increases, which is result (ii) from Proposition 1. We solve the model numerically using value function iteration, assuming an i.i.d. interest rate and parameterizing the model as described in Table B.1.

We choose δ such that the duration of the long-term bond is equal to 10 years. The

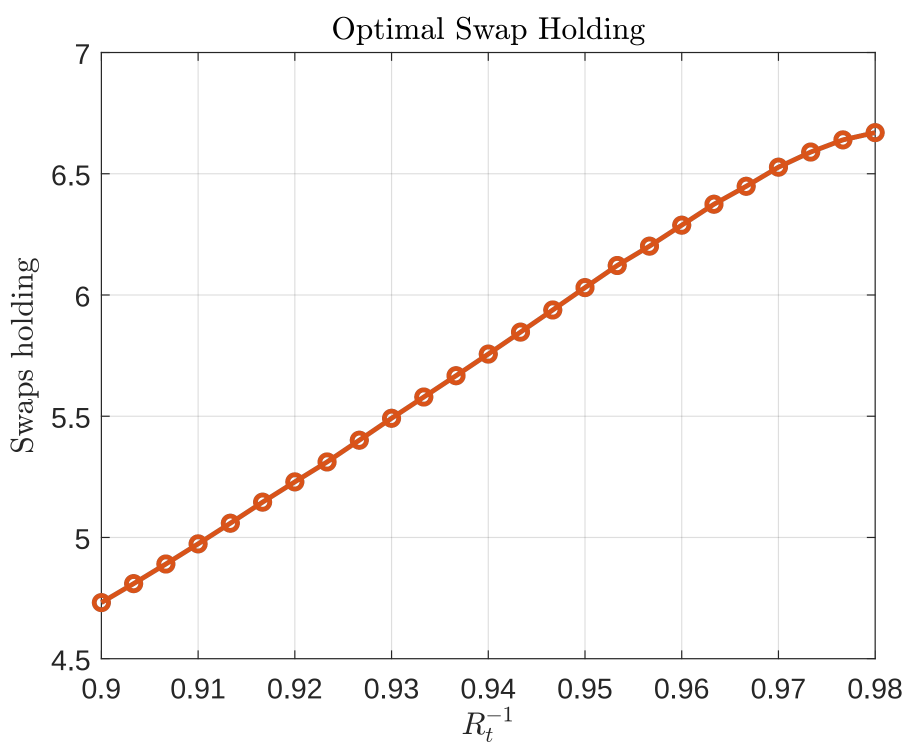
Table B.1 Summary of Parameters

Parameter	Description	Value
c	Cost of liquidation	0.015
δ	Decay rate of long-term bond	0.91
l	Fund payment to its members at each period	0.04
η	Short-term bond premium	0.014
κ	Penalty for fund's deficit	0.3

values for c and η are from Harris and Piwowar (2006) and Nagel (2016), respectively. To show that funds are incentivized to increase their swap holdings after decreases in interest rates, we solve the model for $T = 10$ across a range of interest rates, assuming that R^{-1} has different uniform distributions. These distributions have varying means ranging from 0.9 to 0.98 while maintaining the same variance.

Figure B.1 displays the results, plotting the average s_t against against R^{-1}. As can be clearly seen, low rates (high R^{-1}) are clearly correlated with more demand for hedging.

Figure B.1 Optimal swap holdings across different average values for R^{-1}



B.3 The Linear Hedging Assumption

In our model, the fund is only able to hedge interest rate risk with swaps. This means the hedging strategy is linear. The fund is unable to hedge using non-linear derivatives such as interest rate options. This has important implications for the model's outcomes which we elaborate on here.

Equation (4) provides an insight into the importance of the restricting attention to linear hedging strategies. We repeat here for convenience:

$$\kappa Pr\left\{w_{t+1}<0\right\}\left(\mathbb{E}_t\left[\varepsilon_{t+1}|w_{t+1}<0\right]\right)=\frac{c}{1-c}Pr\left\{m_{t+1}<0\right\}\left(\mathbb{E}_t\left[-\varepsilon_{t+1}|m_{t+1}<0\right]\right). \quad \text{(B.6)}$$

The fund does not care about the payoff from the swap contract in the states of the world where it is neither illiquid nor insolvent. Hence, essentially, what buying the swap does is endow the fund with a valuable put option that pays out when rates fall and the fund has a deficit. This is what the left-hand side of equation (4) captures. The right-hand side captures that buying the swap also forces the fund to sell a call option that is costly to cover in states where the fund is illiquid. Therefore, if the fund could trade the appropriate interest rate options it could, effectively, buy the put without selling the call and so would be able to hedge solvency risk in a manner that avoids illiquidity.

The justification for limiting our attention to linear strategies is twofold. First, implementing an option-based strategy to avoid liquidity risk requires a high degree of financial sophistication and the ability to accurately forecast c (which is problematic if c rises sharply when there is correlated selling). Second, as we show, in practice, hedging strategies are linear. Interest rate options trade in a thin market, are expensive and thus have very limited trading volumes.

B.4 Repo-Based Hedging as a Near-Equivalent to Swaps

This appendix shows how the baseline hedging problem can be implemented using a repo contract rather than an interest rate swap. The key ingredient is that repo is fully margined:

when the value of posted collateral falls, the borrower must deliver liquid assets (variation margin). If repo borrowing cannot be expanded at the moment margin is due, the fund may need to liquidate less liquid assets to meet the margin call. This generates liquidity risk that can materialize even when solvency improves—the defining feature of LASH risk.

Timeline and repo position. To isolate the liquidity mechanism, consider three dates $t, t+1, t+2$. As in the analytical environment in the main text, interest rate risk is realized between t and $t+1$, while for $j \geq 2$ the short rate is constant at $\bar{R}$. The fund enters at date t a repo position backed by the medium-duration bond. Let $x_t \geq 0$ denote the number of units of the medium bond financed via repo.[19] The repo lender applies a haircut $h \in (0,1)$, so the repo borrowing associated with collateral x_t is

$$d_t = (1-h)\, q_t^b\, x_t. \tag{B.7}$$

The borrowed cash is used to increase bond holdings, so that the fund's effective exposure to the medium bond is $b_t + x_t$.

Intermediate-period funding friction. The key friction is that the fund cannot expand repo borrowing at $t+1$. We capture this by assuming $d_{t+1} \leq d_t$, i.e. the fund can unwind or repay repo, but cannot raise additional repo funding in response to a shock.[20]

Repo variation margin and liquidity needs. At date $t+1$, the collateral value is $q_{t+1}^b x_t$. To maintain the haircut, the lender requires $d_t \leq (1-h)\, q_{t+1}^b\, x_t$. If rates rise and the bond price falls, this constraint can be violated, generating a margin call. Define the repo margin call at $t+1$ as the cash required to restore the haircut:

$$VM_{t+1}^{\text{repo}} \equiv \max\Big\{0,\ d_t - (1-h)\, q_{t+1}^b\, x_t\Big\} = (1-h)\, x_t\, \max\Big\{0,\ q_t^b - q_{t+1}^b\Big\}. \tag{B.8}$$

[19]Equivalently, the fund is long x_t units of the medium bond and short a collateralized floating-rate liability. In terms of balance sheet exposure, this is the same economic hedge as receiving fixed and paying floating.

[20]This captures the idea that secured funding supply is state dependent or operationally slow moving, so that the fund cannot reliably meet a sudden margin call by increasing borrowing at the same instant.

This is a liquidity need that arises precisely when yields increase (bond prices fall).

Let liquid resources prior to any bond sales be

$$m^{\text{repo}}_{t+1} \equiv a_t + b_t - l - VM^{\text{repo}}_{t+1}, \tag{B.9}$$

i.e. coupons from the short- and medium-duration assets net of liability payments, minus the repo margin call. If $m^{\text{repo}}_{t+1} < 0$, the fund must sell the medium bond and incur liquidation costs as in the baseline model. Denoting sales at $t+1$ by $\max\{0, \delta(b_t + x_t) - b_{t+1}\}$, the liquidity constraint becomes

$$(1-c)q^b_{t+1} \max\{0, \delta(b_t + x_t) - b_{t+1}\} \geq -\min\{m^{\text{repo}}_{t+1}, 0\}. \tag{B.10}$$

Thus, repo-based hedging creates the same qualitative trade-off as swaps: better hedging of solvency states (rates fall) comes at the cost of larger liquidity needs in states where rates rise.

Near-equivalence with the baseline swap model. Under the analytical interest rate process used in the main text, the price of the medium-duration bond at $t+1$ is affine in the one-period discount factor R^{-1}_{t+1}. In particular, with $R_{t+j} = \bar{R}$ for $j \geq 2$,

$$q^b_{t+1} = R^{-1}_{t+1} + \sum_{j=1}^{\infty} \delta^j \bar{R}^{-(j)} = \text{const} + R^{-1}_{t+1}. \tag{B.11}$$

Since $R^{-1}_{t+1} = R^{-1}_t + \varepsilon_{t+1}$, unexpected increases in yields correspond to $\varepsilon_{t+1} < 0$, which reduce q^b_{t+1} one-for-one. Combining (B.8)–(B.11), the repo margin call is proportional to $-\varepsilon_{t+1}$ in the states where it binds:

$$VM^{\text{repo}}_{t+1} = (1-h)\, x_t \, \max\{0, -\varepsilon_{t+1}\}. \tag{B.12}$$

This is the same state dependence as variation margin on a linear interest rate hedge in the baseline model. In this sense, a repo-financed bond position (with full margining and an inability to expand borrowing at $t+1$) implements a hedge that is near-equivalent to swaps for the purposes of generating LASH risk: it reduces losses when rates fall, but creates liquidity needs when rates rise, potentially forcing costly asset sales.

Interpretation. Repo-based hedging therefore delivers the same economic mechanism emphasized in the baseline model. The fund chooses the size of its hedge (here, x_t) to balance (i) the benefit of reducing insolvency states associated with rate declines, against (ii) the cost of larger margin calls and potential liquidations after sufficiently large rate increases. The intermediate-period repo inflexibility ensures that liquidity risk can bind precisely when solvency improves.

C Institutional Background on UK Pension Funds

The pension fund sector, along with specialized funds servicing it, constitutes a major source of LASH risk in the non-bank sector. Pension funds can be categorized as defined benefit (DB) or defined contribution (DC) funds. Defined benefit pension funds promise a guaranteed return to their beneficiaries upon retirement, while defined contribution funds provide returns that vary based on market performance. By construction, defined benefit funds have higher hedging needs, as they need to meet certain guaranteed payments in the far future. For the UK pension fund system, out of the total £2.2tn of assets under management in Q1 2023, £1.8tn can be attributed to public and private defined benefit funds.[21]

Hedging strategies differ even among pension funds with similar balance sheet structures. They depend on the duration gap, fund type, and the method used to discount future liabilities. Differences in regulations and discounting practices across jurisdictions lead to diverging optimal hedging strategies. For instance, UK pension funds predominantly use gilt yields to discount their liabilities, while Dutch pension funds include the euro interest rate swap rate in their calculations, and US pension funds take a more bespoke approach and use a so-called asset-led discounting methodology. As a consequence, Dutch pension funds almost exclusively hedge using interest rate swaps (Jansen et al., 2023), US pension funds have higher incentives to take on riskier assets as a hedging strategy (Andonov et al., 2017), and in our paper, we find that UK pension funds more frequently use repos than swaps as part of their hedging strategy.

Pension fund market fragmentation also impacts the hedging landscape. In countries with a concentrated market, funds have sufficiently large balance sheets and in-house expertise to design and implement their individual hedging strategies. By contrast, in a fragmented pension fund system, small pension schemes would not have the size or capacity to make in-house hedging a viable solution, giving rise to alternative strategies. A solution is to delegate a part of the portfolio to alternative investment funds, which are designed to attract funds from one (segregated fund) or multiple pension funds (pooled fund). These funds then select their assets, derivatives, and repo leverage based on the desired duration profile of their

[21] See The Office for National Statistics (2023) dataset for details.

clients.

The UK had over 5,300 defined benefit pension schemes in 2022, making it a highly fragmented market.[22] It is, therefore, perhaps unsurprising that the UK saw a rapid rise in alternative investment funds in the recent decade, such as Liability Driven Investment funds (LDIs). In fact, we find that the LASH risk from repo exposures is mainly concentrated in the LDI sector (see Figure II.1), emphasizing the frequent use of repo leverage in this market segment.

D UK Margin Requirements and Market Standards

Margin practices in derivative and repo market changed dramatically following the 2008 financial crisis, driven by wide-reaching regulatory reforms. One of these reforms targeted collateral backing of derivative exposures to mitigate counterparty credit risk. Other reforms aimed to improve credit risk management through better collateral management in securities financing transactions, and so, short-term money markets.

Interest rate risk can affect both derivatives and repo transactions through different channels. The value of an interest rate swap contract changes as the underlying market rate of the specified index (e.g., LIBOR, SONIA) changes, implicitly affecting counterparty credit risk. In addition, in a collateralized transaction, when the value of the underlying collateral changes as interest rates change (e.g., a government bond), the credit risk of the transaction changes as well. A common practice to mitigate these two risks—by regulation or choice—is regular margin posting.

Definition – initial margin and variation margin

In derivatives trading, margin requirements were introduced as part of post-GFC reforms to mitigate systemic risk. There are two types of margining: initial margin (IM) and variation margin (VM). Initial margin serves to protect parties from potential future exposure that may arise between a counterparty's default and the subsequent closing out of positions. It is recalculated regularly to account for changing risks. Typically, IM includes a core component

[22] See Pension Regulator Annual report.

related to market risk and factors in additional risks, such as liquidity and concentration risk (BCBS and IOSCO, 2022).

Additionally, derivative users are required to settle changes in the trade's market value at least once daily through VM. Therefore, VM reflects the mark-to-market process, ensuring that positions are reset to a net value of zero after each payment (BCBS and IOSCO, 2020).

Margin practices for centrally and non-centrally cleared derivatives

Both centrally cleared and non-centrally cleared (bilateral) trades are subject to margin requirements. Since mid-2016, interest rate derivatives in certain currencies, including the pound sterling, have been subject to mandatory clearing, with phase-ins based on firm classifications and derivative volumes. The majority of trades in our sample fall under these mandatory clearing requirements. Globally, over 75% of all interest rate derivatives were centrally cleared in 2023 (BIS, 2023).

Both IM and VM are mandatory for centrally cleared trades, with specific requirements determined by central counterparties' (CCP) margin models. In UK clearing houses, variation margin is generally required to be posted in cash, though there are exceptions based on CCP-specific rules. For example, at LCH, intraday VM requirements can be met using excess pre-positioned initial margin. Unlike the stricter VM rules, there is more flexibility regarding initial margin. IM can be posted in cash or highly liquid non-cash collateral, depending on the rules of the specific CCP (BCBS and IOSCO, 2022).

Cash collateral offers advantages, such as lower haircuts (Benos et al., 2022). During periods of high market volatility, the preference for cash increases further due to rising haircuts and greater price volatility in other assets. While VM is typically exchanged at the end of the trading day, CCPs have the discretion to issue margin calls more frequently, especially in times of heightened volatility. For example, intraday margin calls surged during the "Dash for Cash" episode in March 2020 (BCBS and IOSCO, 2022).

For non-centrally cleared (bilateral) trades, counterparties may choose not to clear trades through a central counterparty if the derivatives and counterparty types do not fall under mandatory clearing requirements. In such cases, the Basel Committee on Banking Supervision (BCBS) and the International Organization of Securities Commissions (IOSCO) require that all financial counterparties and systemically important non-financial counterparties exchange VM for new trades initiated after March 1, 2017. Additionally, they must exchange IM if both counterparties are part of groups with a month-end average gross notional amount of non-centrally cleared derivatives of at least EUR 8 billion (BCBS, 2013).

This IM requirement was phased in and applies only to contracts entered into once the counterparties' outstanding gross notional exceeds the phased-in threshold for that month (see PS14/21 for details). The UK implementation specifies a list of eligible assets that financial and non-financial counterparties within scope can use to meet VM and IM requirements, including cash and specific assets subject to haircuts. However, for vanilla derivatives and standard agreements, it is likely that cash will be the preferred collateral for VM due to its frequent exchange requirements.[23]

Is the exchange of VM mandatory?

The obligation to post VM is always mandatory, with no discretion to waive this requirement. For centrally cleared trades, this includes the additional obligation to post VM exclusively in cash.

Where does the cash go?

Collateral collected by central counterparties (CCPs) is subject to strict and limited redeployment rules. IM is paid by both counterparties to the CCP, as required under Article 47 of EMIR, and is segregated in clearing member and client accounts. This ensures that, in the event of a CCP default, members will recover exactly the IM collateral they initially provided. In contrast, VM is passed directly through the CCP to the end-users. The counterparty that is out of the money pays VM to the CCP, which then transfers it to the counterparty that is in the money.

UK EMIR regulations require that at least 95% of cash positions in a CCP's margin account held overnight must be invested in safe and liquid assets. In the UK, CCPs are permitted to invest only in reverse repos, government bond purchases, and central bank deposits (Article 43 of UK EMIR). Given the short-term nature of margin calls, CCPs

[23] For rules on OTC derivatives not cleared by a CCP, see UK EMIR Art 11, and for eligible non-financial counterparties, see UK EMIR Art 10. The asset classes subject to mandatory clearing are outlined in the Technical Standards referenced in UK EMIR Art 5(2).

primarily invest in reverse repos (for a detailed discussion on CCP collateral usage, see Benos et al., 2022). In contrast, there are no specific restrictions on how VM transferred to end-users can be used, to the best of our knowledge.

For non-centrally cleared trades, regulation mandates that IM must be segregated with a third-party holder or custodian, and the collecting counterparty is generally prohibited from rehypothecating, repledging, or reusing the collected IM, with a few exceptions (see Articles 19 and 20 of BTS 2016/2251). Similar to centrally cleared trading, VM can be redeployed and is only required to be segregated if the posting counterparty requests it (see Article 19.5 BTS 2016/2251). However, since VM is exchanged daily and counterparties may need it for liquidity purposes to meet future VM calls, it is likely that cash is used for limited investment opportunities, such as reverse repos.

Magnitudes: VM outweighs IM

Daily VM calls are typically much larger in magnitude than IM calls for both centrally cleared and non-centrally cleared trades, making VM the primary driver of liquidity needs. For example, aggregate VM calls across clearing members can be up to six times higher than IM calls (Czech et al., 2021).

During periods of stress, such as the onset of the COVID-19 pandemic, daily VM calls by CCPs surged from $25 billion in February 2020 to $140 billion on March 9, 2020, while the peak for IM calls was only half of that (BCBS and IOSCO, 2022). Similarly, at UK clearing houses, non-bank financial intermediaries faced VM calls exceeding £13 billion, while their IM demand rose by only £2.4 billion (Czech et al., 2023).

Differences with repo margining practices

Repurchase agreements are a type of Securities Financing Transaction (SFT) and are not subject to mandatory margining requirements like derivative contracts. Instead, they fall under Credit Risk Mitigation regulations, and counterparties are expected to adhere to best margining practices established by industry bodies (see, e.g., ICMA, 2023).

Best practices for repo margining align closely with those for derivatives, though they are generally less stringent. The International Capital Market Association (ICMA) recommends at least daily re-evaluation of net exposures, exchanges of VM, and delivery of cash margin on the same day that a margin call is made. Additionally, firms are encouraged to clear existing margin accounts (either paid or received) before issuing new margin calls.

These calls can be satisfied with cash or securities that are acceptable as general collateral in the repo market, or with securities that possess equal or superior characteristics to the original collateral posted. In practice, this often limits the options to High-Quality Liquid Assets (HQLA). Furthermore, counterparties have the option to delegate collateral and margin management to a third party, allowing custodians to handle margin calls in a manner similar to derivatives practices.

Supervisory market intelligence suggests that the best practice rules for margining are largely followed, particularly for gilt-based repos.

E Pension Funds' Trading Duration and Duration Gap

In Section 5, we show that falling interest rates lead to an economically and statistically significantly higher LASH risk taken by institutions with short asset duration. Technically, rather than asset duration, the duration gap between assets and liabilities is what matters for solvency. In the absence of granular information on the duration of institutions' liabilities, however, we use institutions' initial gross asset duration, proxied via the average maturity of gilts traded in 2018. To test the correlation between gross duration and the duration gap, we use our hand-collected balance sheet data for UK pension funds.

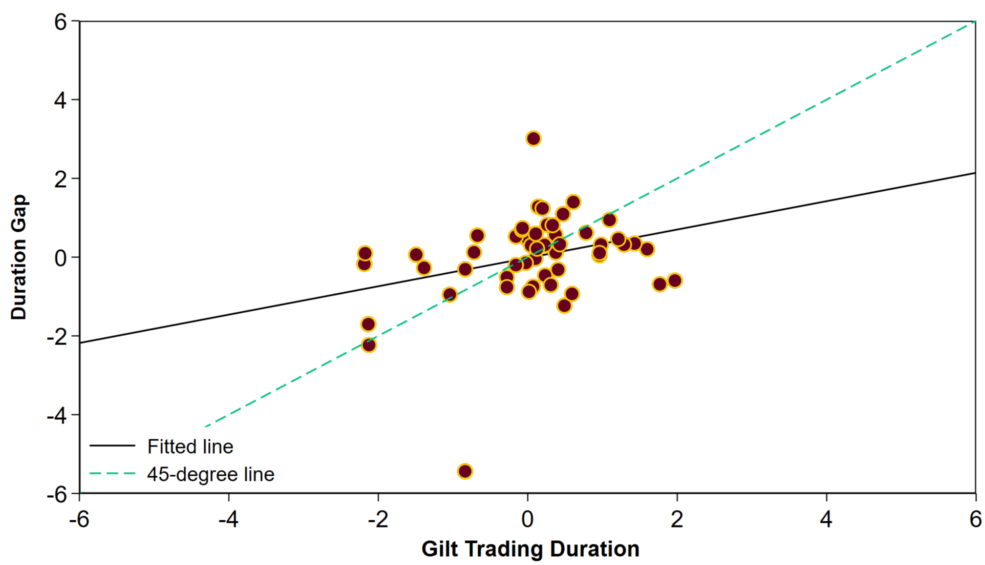
First, we measure the duration gap of pension funds. To do so, we estimate the sensitivity of the funding ratios of individual pension funds to changes in the ten-year UK gilt yield using seemingly unrelated regressions:

$$\Delta FundingRatio_{j,t} = \alpha + \beta_f \Delta Yield_t + \varepsilon_{j,t}, \tag{E.1}$$

where $\Delta FundingRatio_{j,t}$ measures the annual change in the natural logarithm of pension fund j's funding ratio—which is defined as the value of the fund's assets over liabilities—in year t. $\Delta Yield_t$ is the annual change in the ten-year UK gilt yield. The negative of β_f is our measure of the funds' duration gap, so that more negative values indicate a larger asset–liability mismatch and greater exposure of solvency to interest rate risk.

Appendix Figure E.1 shows a scatter plot relating our estimate of fund-level duration gap to the trading duration of these funds. Each are in standardized units, the duration gap estimates on the vertical axis, and the gilt trading-based duration on the horizontal axis. The association is clearly positive, even though the number of matched funds is relatively small. In other words, the funding ratio of funds with shorter trading duration is more sensitive to a change in yields (indicating a wider duration gap)—and hence the solvency of these funds will decrease more sharply in response to lower interest rates relative to funds with longer asset duration.

Figure E.1 Trading Duration and Duration Gap



NOTE. This figure shows a scatter plot of individual pension funds' duration gap (defined as the negative of the sensitivity of funds' annual log change in funding ratios to changes in the yield of the ten-year UK gilt yield), and the funds' gilt trading-based duration. Each are in standardized units, the duration gap estimates on the vertical axis, and the gilt trading-based duration on the horizontal axis. Funding ratios are the ratio of pension funds' market value of assets to liabilities.

Documenting this relation more formally, Table E.1 presents the first-stage results of the IV regression in column (6) of Table 2. The first-stage results confirm that the gilt trading–based asset duration is a relevant instrument for pension funds' duration gap. The instrument enters positively and significantly, with a Kleibergen–Paap F-statistic of 7.14. The Kleibergen–Paap LM test rejects the null of underidentification ($p = 0.02$). The Anderson–Rubin p-value of 0.09 indicates that the effect is identified under robust inference,

Table E.1 Rates and Institution-level LASH Risk — First Stage

	(1)
	$\Delta Yield^{10Y}$ × Trading Duration
$\Delta Yield^{10Y}$ × Duration Gap	0.34**
	(0.13)
Observations	733
R squared	0.555
Number of Institutions	51
Kleibergen-Paap F-statistic	7.14
Kleibergen-Paap LM p-value	0.02
Anderson-Rubin Test p-value	0.09
Time FE	yes
Institution FE	yes
Institution-Yield Slope FE	yes

Note. This table reports the first-stage results of the IV regression in Column (6) of Table 2. We use our gilt trading-based asset duration measure as an instrument for pension funds' net duration gap. We also include leverage (log of net repo borrowing) and size (log of total assets), each interacted with the quarterly change in the 10-year gilt yield, as additional controls. We report the Kleibergen-Paap F-statistic, Kleibergen-Paap LM p-value, and the Anderson-Rubin Test p-value. The regression is weighted by fund size. Standard errors are clustered at the institution level. *** p<0.01, ** p<0.05, * p<0.1. Coefficients corresponding to the constant, control variables and fixed effects not reported.

although with moderate statistical strength. Overall, the results emphasize the positive correlation between funds' duration gap and trading duration, and support our choice of gilt trading-based duration as a viable instrument for pension funds' duration gap.

To alleviate concerns that our duration measures may inadvertently proxy for other balance sheet characteristics, we split the sample into two groups based on whether a fund's trading duration, duration gap or repo collateral duration lies above or below the sample median and compare their observable characteristics for the year 2023. Table E.2 shows that, across all categories, differences between short- and long-duration funds are economically modest and statistically insignificant. The different groups exhibit similar sizes, liability structures, and asset compositions, indicating that the duration split does not mechanically capture other observable fund characteristics. This supports our interpretation that the variation in our duration measures reflects differences in solvency exposure to interest rate risk rather than other balance sheet characteristics.

Table E.2 Balance Table for Pension Funds' Duration Measures

	Short mean	Short N	Long mean	Long N	Diff (L-S)	p-value
Panel A: Trading Duration						
Actuarial value of assets	5359	29	7198	29	1839	0.55
Actuarial value of liabilities	5197	29	6660	29	1463	0.61
Investment liabilities	1771	24	1646	22	-125	0.85
Derivatives liabilities	658	24	482	22	-177	0.70
Investment assets	8167	24	9845	22	1677	0.71
Bonds	4272	24	4971	22	699	0.74
Pooled investment vehicles	2443	24	1996	22	-448	0.69
Derivatives assets	436	24	391	22	-45	0.85
Cash and cash equivalents	124	24	231	22	106	0.41
Panel B: Duration Gap						
Actuarial value of assets	8498	26	4623	25	-3875	0.25
Actuarial value of liabilities	8045	26	4328	25	-3717	0.24
Investment liabilities	1927	22	1333	20	-595	0.40
Derivatives liabilities	683	22	400	20	-283	0.56
Investment assets	10842	22	7023	20	-3818	0.41
Bonds	5418	22	3655	20	-1763	0.42
Pooled investment vehicles	2542	22	1993	20	-549	0.66
Derivatives assets	420	22	313	20	-107	0.67
Cash and cash equivalents	236	22	120	20	-116	0.38
Panel C: Repo Collateral Duration						
Actuarial value of assets	5836	22	4944	21	-892	0.80
Actuarial value of liabilities	5387	22	4693	21	-695	0.83
Investment liabilities	1073	16	1774	16	701	0.28
Derivatives liabilities	350	16	332	16	-19	0.94
Investment assets	8295	16	6498	16	-1796	0.74
Bonds	3770	16	3723	16	-46	0.98
Pooled investment vehicles	1749	16	1524	16	-226	0.83
Derivatives assets	290	16	353	16	63	0.76
Cash and cash equivalents	179	16	90	16	-88	0.58

Note. This table reports differences in the average size of different balance sheet items (in £m) between pension funds sorted into two groups (split at the sample median) based on gilt trading-based duration, with *Short* indicating short trading duration and *Long* indicating long trading duration (Panel A); estimated duration gap, with *Short* indicating wide duration gaps and *Long* indicating narrow duration gaps (Panel B); and repo collateral duration, with *Short* indicating short repo collateral duration and *Long* indicating long repo collateral duration (Panel C). The year of reporting is 2023. For each variable, we report the mean for the two groups, the corresponding number of observations (N), the difference in means (Group 2 minus Group 1), and the two-sided p-value from a Welch t-test.

Internet Appendix

I LASH Risk from Interest Rates: Measurement for Repo Contracts and Interest Rate Swaps

In this section, we apply equation (5) to repos and interest rate swaps.

Repos As explained in the previous section, repos are short-dated collateralized borrowing arrangements that allow institutions to shorten the duration of their liabilities. The majority of repo transactions are overnight, but pension funds and other interest rate hedgers predominantly use term repos with a maturity of one month or more. LASH risk arises via price changes of the underlying collateral. As the collateral value decreases, ceteris paribus, a counterparty would need to pledge more collateral (or cash) to be able to borrow the same amount.

We approximate LASH risk for repos using the modified duration of the underlying collateral, which measures the impact of a 100bps change in interest rates on the value of the bond. Therefore, in the context of repo, LASH risk resembles the conventional DV01 (or "dollar duration"). For each contract i with bond collateral b of maturity m years and coupon payments c times a year, LASH risk for a 100bps increase in interest rates at time t reads:

$$LASH_{i,t}^{Repo} = \frac{Q_{i,t}}{100} \times \underbrace{\frac{\sum_{k=1}^{K}(1+r_t)^{-k_b} \cdot CF_{b,k} \cdot k_b}{P_{b,t}} \times \left(1 + \frac{YTM_{b,t}}{c_b}\right)^{-1}}_{\text{Modified duration of bond } b} \tag{I.1}$$

where $Q_{i,t}$ is the borrowing amount of a given repo contract. $P_{b,t}$ is the market price of bond b, k_b is the time to each cash flow $CF_{b,k}$ of bond b from time t perspective (in years), and $YTM_{b,t}$ is the bonds' yield to maturity. We assume zero haircuts as most of the LASH risk in our sample is due to longer-term repos, which are, of course, less frequently rolled over compared to overnight contracts (where haircuts play a bigger role, e.g., during the Great Financial Crisis). This implies a one-to-one liquidity need with respect to the cash flow sensitivity to interest rates, hence $\Lambda_i = 1$.

Interest Rate Swaps An interest rate swap is a contract where two counterparties agree to exchange a fixed interest rate for a variable one, e.g., LIBOR, SOFR, SONIA, c times a year, for a duration of m years. The interest is calculated on a notional amount, Q, but only the difference in interest payments is exchanged. The fixed interest rate is set so that the NPV of the contract is zero at initiation; that is, neither side needs to pay the other to enter the agreement. To mitigate counterparty credit risk, parties entering a swap must pledge liquid collateral as initial margin.

LASH risk arises in swaps mainly due to variation margin. The counterparties are required to exchange variation margin on a daily basis to maintain the zero net present value of the contract as interest rates change. The floating rate payer will post variation margin to the fixed rate payer when rates rise (and vice versa when rates fall). In practice, this is implemented through daily (cash) margin calls that reflect the change in the mark-to-market price of the contract.[24]

The size of the margin calls, and the demand for liquidity, depend on the sensitivity of the swap's fixed versus floating cash flows to changes in interest rates. We extend the methodology proposed by Bardoscia et al. (2021) to calculate the liquidity needs from a given interest rate move and hence to obtain an estimate of LASH risk. Imagine an interest rate swap of net notional value Q. We are at time zero and the swap matures at year T, and makes c coupon payments per year. Let k index coupon periods. There is a swap curve which defines the time zero sequence of annualized forward floating rates given by $r_{k,k-1}$, and a fixed rate $\bar{r}$ (for an at the money swap ($\bar{r} \equiv r_{T,0}$)). Cash-flows are discounted at rate:

$$d_k = (1 + \frac{r_{k,0}}{c})^{-k} \approx e^{-\frac{r_{k,0}}{c}k}$$

The present value of the floating and fixed leg of the swap is given by:

$$PV_{floating} = Q \sum_{k=1}^{cT} d_k \frac{r_{k,k-1}}{c}$$

[24] Variation margin is a regulatory requirement, and the requirements may differ between centrally-cleared and bilateral swaps. A centrally cleared swap requires daily cash pledges for variation margin, while bilateral swaps can have more bespoke conditions if permitted by regulation, e.g., the use of non-cash collateral.

$$PV_{fixed} = Q \sum_{k=1}^{cT} d_k \frac{\bar{r}}{c}$$

Now the NPV of the contract for the floating rate payer is given by:

$$NPV = PV_{fixed} - PV_{floating} = \frac{Q}{c} \sum_{k=1}^{cT} d_k (\bar{r} - r_{k,k-1}).$$

For a ex post shift upwards of the swap curve, the sensitivity reads:

$$\frac{\partial NPV}{\partial r} = -\frac{Q}{c} \sum_{k=1}^{cT} \left[\underbrace{d_k + \frac{\partial d_k}{\partial r} r_{k,k-1}}_{\text{change in value of floating leg}} - \underbrace{\frac{\partial d_k}{\partial r} \bar{r}}_{\text{change in value of fixed leg}} \right]. \tag{I.2}$$

Solving in continuous time yields:

$$\frac{\partial NPV}{\partial r} = -\frac{Q}{c} \sum_{k=1}^{cT} \left[d_k + \frac{k}{c} d_k (\bar{r}_i - r_{k,k-1}) \right].$$

Hence, LASH risk from a 100bps increase in interest rates for a swap contract i with maturity T based on notional Q and with c cash flow swaps a year reads:

$$LASH^{IRS}_{i,t} = \frac{Q_i}{100c} \sum_{k=1}^{cT} \left[d_k + \frac{k}{c} d_k (\bar{r}_i - r_{k,k-1}) \right]. \tag{I.3}$$

where the discount rate for cash flow k, $e^{-R_{k,t} \cdot (T_k - t)}$, is evaluated based on the daily Overnight Index Swap (OIS) yield curve for maturity $T_k - t$ from time t perspective. We derive the forward rates $r_{k,k-1}$ as implied by the OIS curve. We assume the fixed rate to be the prevailing OIS rate at the start of contract i corresponding to the trade maturity. Lastly, standard contracts have semi-annual coupons, so $c = 2$, without loss of generality.The LASH risk for swaps through the variation margin implies a one-to-one liquidity need with respect to the cash flow sensitivity to interest rates, hence $\Lambda = 1$.

US Insurers Internet Appendix Figure II.9 reports LASH Risk, measured in billions of U.S. dollars, for U.S. life insurers over the period 2019–2024. The figure is constructed using quarterly, contract-level derivative positions reported by U.S. life insurers in NAIC Schedule DB, obtained via S&P Capital IQ Pro. We restrict the sample to U.S. dollar–denominated interest rate swaps.

We identify the direction of each trade (paying or receiving the fixed rate) using textual analysis when possible. When textual information is insufficient, we infer trade direction by comparing changes in the mark-to-market value of the position with changes in the maturity-matched zero-coupon U.S. Treasury yield over time. We retain only trades for which the sign of the mark-to-market change aligns consistently with the sign of the yield change—either moving in the same direction or in opposite directions—in at least 80% of the observations for that trade.

We further restrict the analysis to life insurers for which we can consistently classify at least 70% of their trades over the sample period. LASH Risk is then estimated following the methodology described above, assuming annual coupon payments. The OIS curve is obtained from Bloomberg and extrapolated beyond the 10-year tenor.

II Data: Additional Information & Summary Statistics

This section of the Appendix provides additional information and summary statistics for the various data sources used in the empirical analysis.

Table II.1 SUMMARY STATISTICS: UK PENSION FUND BALANCE SHEETS

	2019	**2020**	**2021**	**2022**	**2023**
N	70	77	82	91	87
Total assets (£bn)	870.0	1027.5	992.5	999.2	452.8
Total liabilities (£bn)	872.6	1075.7	936.8	930.5	426.7
Actuarial assets (£m)					
Min	65	62	72	60	18
Mean	12253	13174	12104	10980	5205
Median	3225	3192	3403	2455	2106
Max	395867	444167	463022	406597	73100
Std deviation	47328	51058	51658	43641	10107
Actuarial liabilities (£m)					
Min	83	95	92	64	13
Mean	12466	13970	11425	10225	4905
Median	3297	3499	3381	2537	2117
Max	404974	475130	418665	366574	66100
Std deviation	48808	55064	46932	39602	9382

NOTE. Cross-sectional dispersion and total actuarial values and liabilities for the UK pension funds in our hand-collected sample. Values are reported in £m, unless otherwise stated, and N denotes the total number of pension funds in each year of our sample.

Table II.2 SUMMARY STATISTICS: UK PENSION FUND FUNDING RATIOS

	2019	**2020**	**2021**	**2022**	**2023**
N	73	81	87	91	91
Underfunded PFs	0.53	0.59	0.36	0.29	0.30
Pension fund funding ratios					
Min	0.74	0.63	0.68	0.73	0.82
Mean	0.99	0.97	1.02	1.05	1.04
Median	0.99	0.98	1.02	1.04	1.04
Max	1.40	1.49	1.54	1.42	1.38
Std. deviation	0.12	0.13	0.12	0.10	0.09

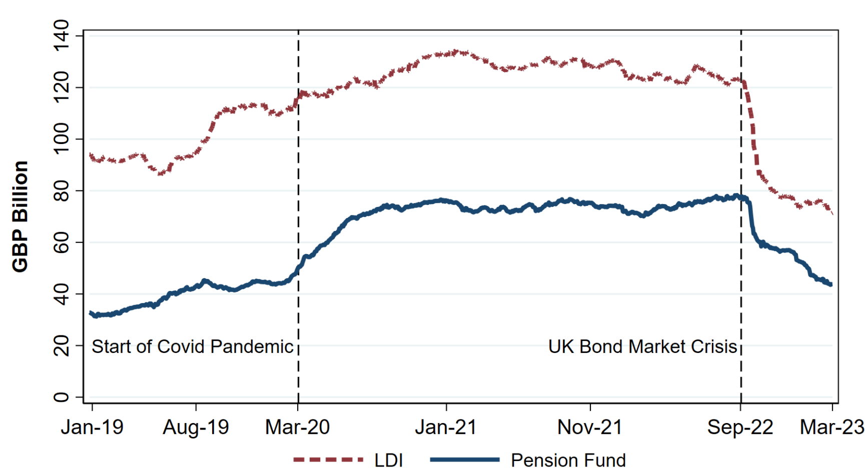
NOTE. Cross-sectional dispersion of funding ratios for the UK pension funds in our hand-collected sample. N denotes the total number of pension funds in each year of our sample, and the underfunded PFs denotes the share of pension funds with a negative funding ratio (so assets<liabilities) in the given year. A ratio of 1 indicates that the actuarial value of assets exactly matches the actuarial value of liabilities.

Table II.3 SUMMARY STATISTICS: AVERAGE NET POSITIONS AND LASH RISK

	Repo net borrowing					IRS net receive fixed				
Sector	2019	'20	'21	'22	'23	2019	'20	'21	'22	'23
Pension fund	38	64	74	69	48	65	96	101	132	112
LDI	99	121	130	113	73	17	37	40	38	23
Insurer	0	0	0	0	0	10	23	27	72	60
Hedge Fund	-7	11	-3	-34	-15	59	82	-14	-108	-81
Fund	9	7	7	4	4	23	21	11	18	15
Other financial	7	20	18	10	5	-8	-11	-3	-9	-14
	Repo discretionary LASH					**IRS discretionary LASH**				
Sector	2019	'20	'21	'22	'23	2019	'20	'21	'22	'23
Pension fund	8	15	18	16	11	5	11	12	12	10
LDI	22	28	30	26	17	2	5	5	5	3
Insurer	0	0	0	0	0	0	6	6	8	7
Hedge Fund	0	1	-1	-3	-1	1	0	-1	-1	-1
Fund	2	1	1	1	1	2	1	1	0	0
Other financial	2	4	3	2	1	-2	-2	-1	-1	-1

NOTE. Sample: Summary statistics on repo and IRS positions from 2019 to 2023. Values reported in £bn. Repo net borrowing captures the daily average cash borrowing per sector in a given year. The IRS net position captures the average holding of net receive fixed positions (negative values read as net pay fixed) per sector in a given year. Behavioural LASH risk captures the average for each sector in a given year.

Figure II.1 PENSION & LDI FUNDS' REPO NET BORROWING STOCKS



NOTE. Aggregate repo net borrowing stocks of UK pension and LDI funds in £bn. Source: Sterling Money Market data collection.

Table II.4 Summary Statistics: Cross-sectional variation of Net positions and LASH risk

		Repo net borrowing			Repo discretionary LASH		
Sector	N	Mean	Median	Std dev	Mean	Median	Std dev
Pension fund	273	259.3	144.3	388.3	59.4	31.5	89.3
LDI	337	360.6	113.6	1275.5	82.6	25.5	300.6
Insurer	16	45.2	36.7	205.3	6.3	3.6	43.4
Hedge Fund	284	-59.7	-0.6	561.4	-4.0	0.0	65.6
Fund	203	117.6	3.7	626.6	22.9	0.6	143.7
Other financial	13	-10.5	0.0	116.7	-1.1	0.0	21.1
		IRS net receive positions			**IRS discretionary LASH**		
Sector	N	Mean	Median	Std dev	Mean	Median	Std dev
Pension fund	450	297.9	32.0	1372.2	29.9	2.6	183.9
LDI	231	199.3	48.2	477.1	24.9	3.0	72.6
Insurer	76	971.4	17.0	4034.6	139.2	0.2	691.3
Hedge Fund	149	-231.0	10.0	19493.3	-7.4	0.0	186.4
Fund	869	54.2	0.8	565.0	2.6	0.0	29.4
Other financial	217	-148.8	-6.5	1266.4	-14.1	-0.2	107.3

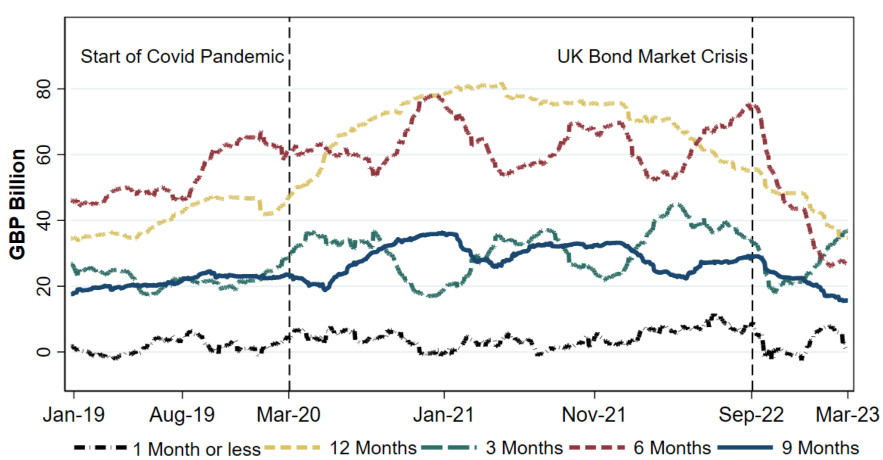
Note. Sample: Firm level summary statistics for repo (2017-2023) and IRS positions (2019-2023). Values are reported in £m, and N denotes the number of firms in each sector of our sample. The mean and median of repo net borrowing capture the total daily cash borrowing in the cross-section, and the IRS net position captures the outstanding net receive fixed positions (negative values read as net pay fixed). Behavioural LASH risk measures the outstanding LASH exposure at firm level in a given day.

Table II.5 LASH risk and Gilt Trading Volumes - Pension & LDI Funds only

	(1)	(2)	(3)	(4)
	Net Volume		Sell Volume	
LASH combined	-0.12**		0.10***	
	(0.05)		(0.02)	
LASH Repo		-0.10***		0.08***
		(0.03)		(0.02)
LASH IRS		-0.04		0.05
		(0.07)		(0.04)
Observations	2325	2325	2325	2325
R squared	0.036	0.036	0.044	0.044
Day FE	yes	yes	yes	yes

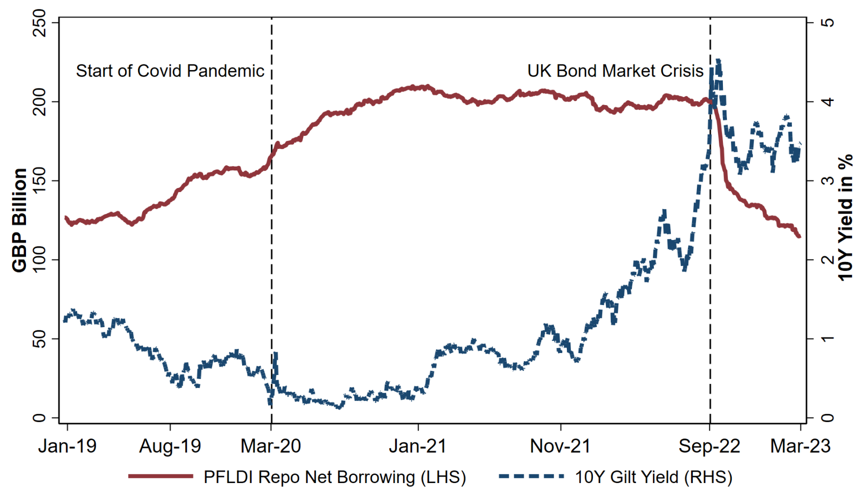
Note. For each pension & LDI fund, as defined in equation 7 in Section 3.2, "LASH" is measured as the potential liquidity needs following a 100bps shift in gilt yields, either for repo and IRS exposures combined, or separately for both instruments. The dependent variable is the institution's daily gilt net trading volume on day t in Columns (1) and (2), and the institution's sell volumes on day t in Columns (3) and (4). The dependent variables are transformed using the Inverse Hyperbolic Sine method. The LASH variable is standardized. Clustered standard errors on the day level are reported in parentheses. We include day fixed effects. *** p<0.01, ** p<0.05, * p<0.1. Coefficients corresponding to the constant, control variables and fixed effects not reported.

Figure II.2 Pension & LDI Funds' Repo Net Borrowing Stocks by Maturity



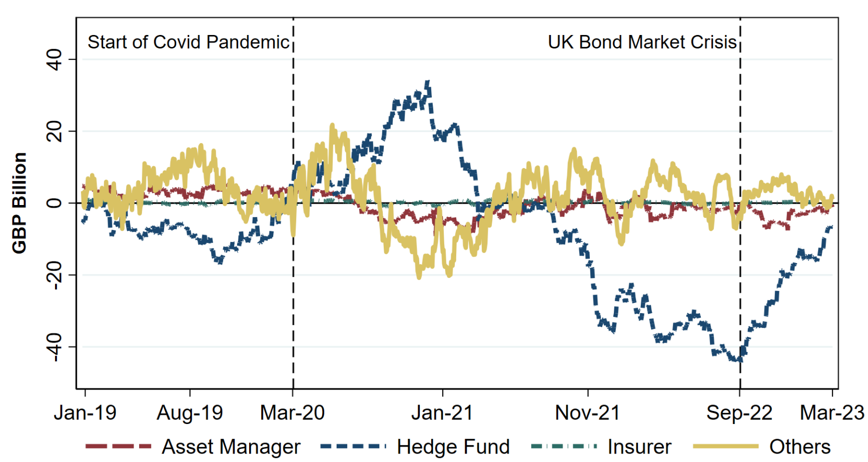
NOTE. Aggregate repo net borrowing stocks of UK pension and LDI funds by the maturity bucket at initiation in £bn. Source: Sterling Money Market data collection.

Figure II.3 Pension & LDI Funds' Repo Net Borrowing Stocks & 10Y Gilt Yields



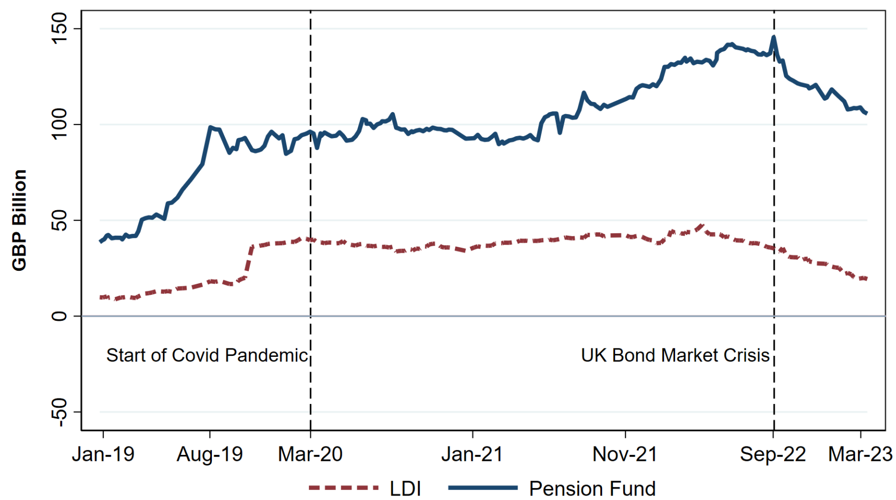
NOTE. Aggregate repo net borrowing stocks of UK pension and LDI funds in £bn and 10-year gilt yields in %. Source: Sterling Money Market data collection & Bank of England.

Figure II.4 Repo Net Borrowing Stocks Across Other Non-Bank Sectors



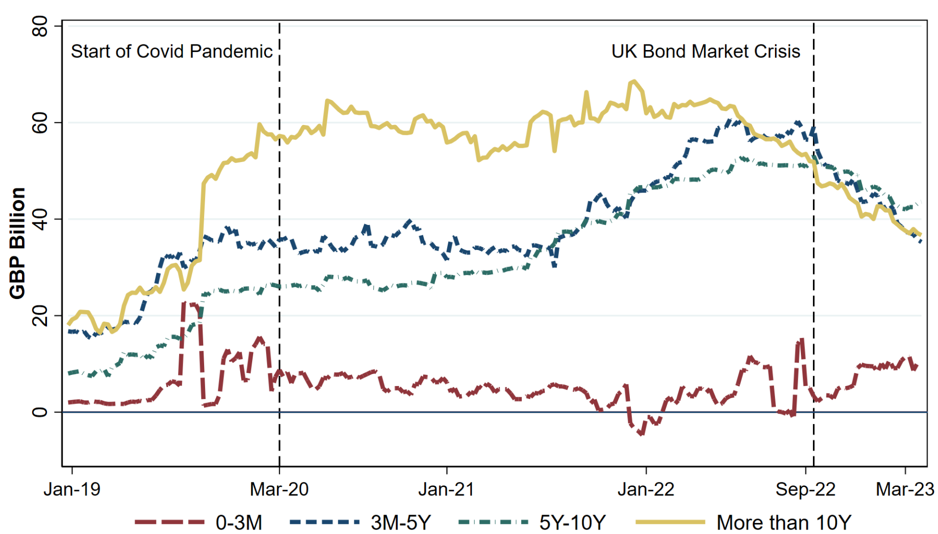
NOTE. Aggregate repo net borrowing across all sector types in £bn. "Others" include sovereign entities and other financials. Source: Sterling Money Market data collection.

Figure II.5 Pension & LDI Funds' IRS Net Notionals



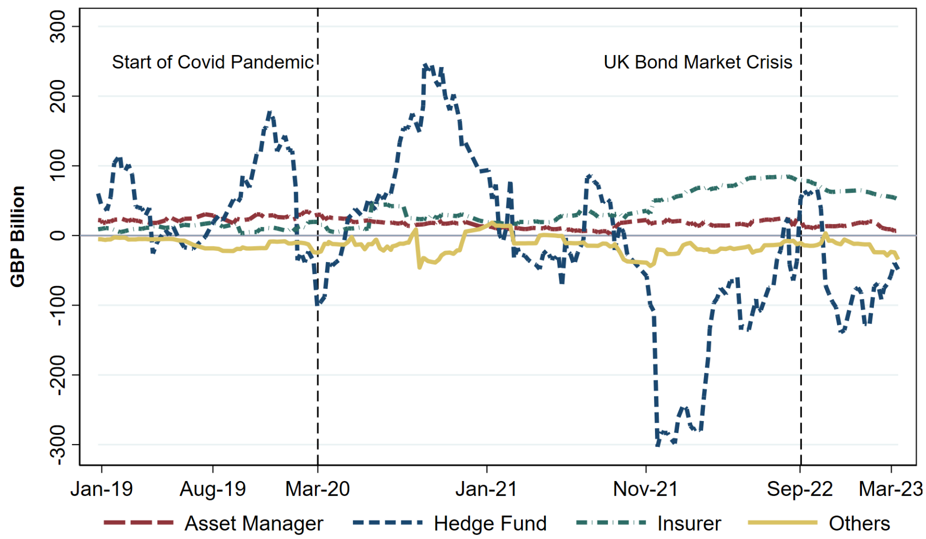
NOTE. Aggregate IRS net notionals of UK pension and LDI funds in £bn. Source: EMIR Trade Repository Data.

Figure II.6 Pension & LDI Funds' IRS Net Notionals by Maturity



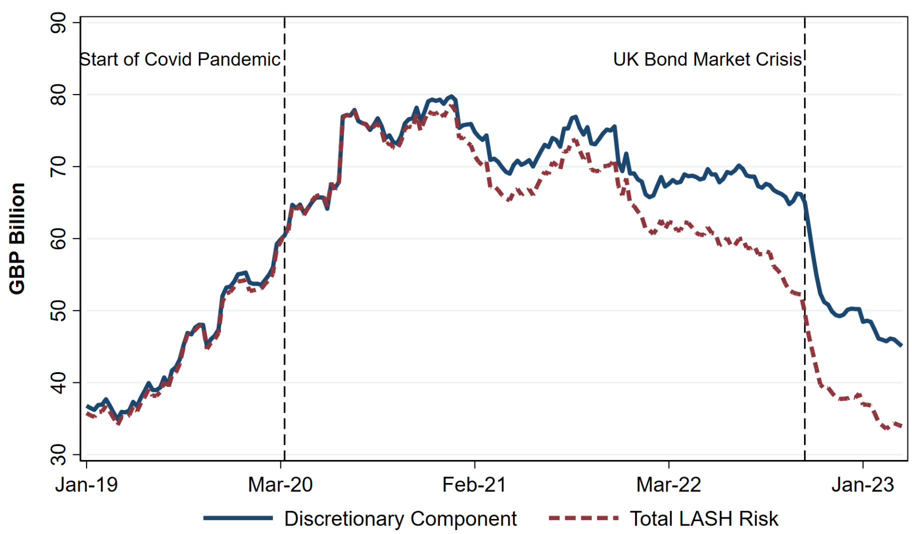
NOTE. Aggregate IRS net notionals of UK pension and LDI funds by maturity bucket in £bn. Source: EMIR Trade Repository Data.

Figure II.7 Irs Net Notionals Across Other Non-Bank Sectors



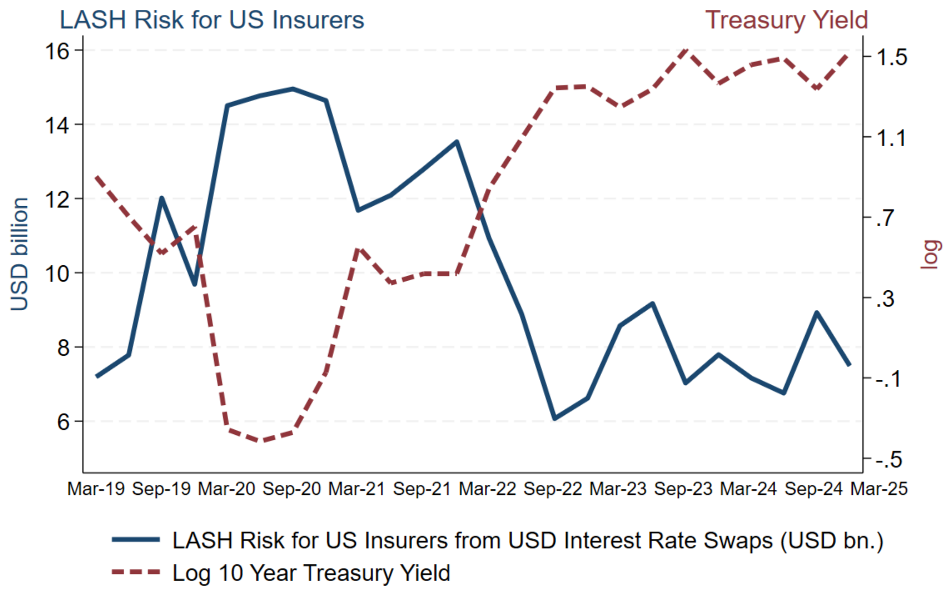
NOTE. Aggregate IRS net notionals across all sector types in £bn. "Others" include sovereign entities and other financials. Source: EMIR Trade Repository Data.

Figure II.8 LASH: Discretionary Component



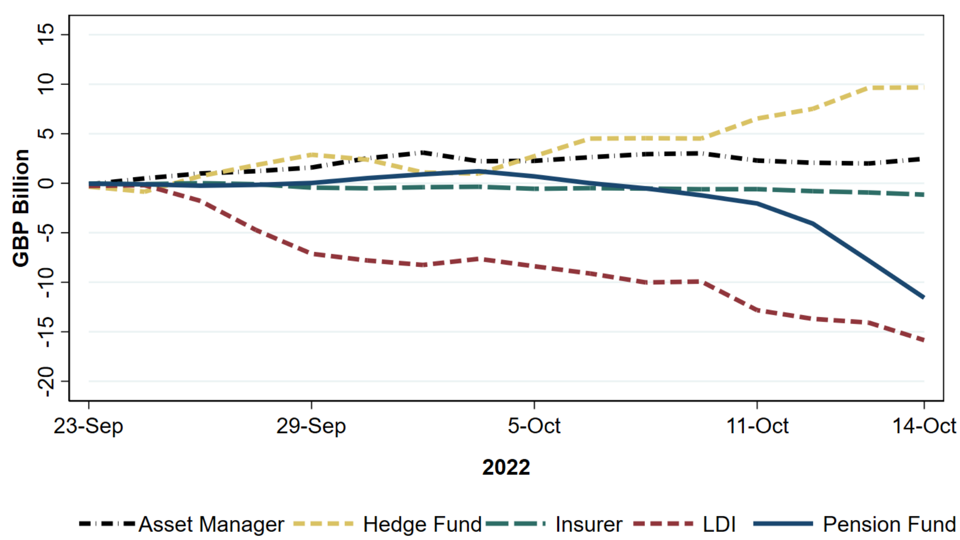
NOTE. This figure shows the evolution of the total LASH risk and the discretionary LASH risk component in £bn for all non-banks. The *Discretionary Component* is defined as $\sum_i \text{LASH}_{i,t-1}\Delta Q_{i,t}$ for interest rate swaps and repos, as shown in equation 8 in Section 3.2.

Figure II.9 LASH Risk: US Insurers



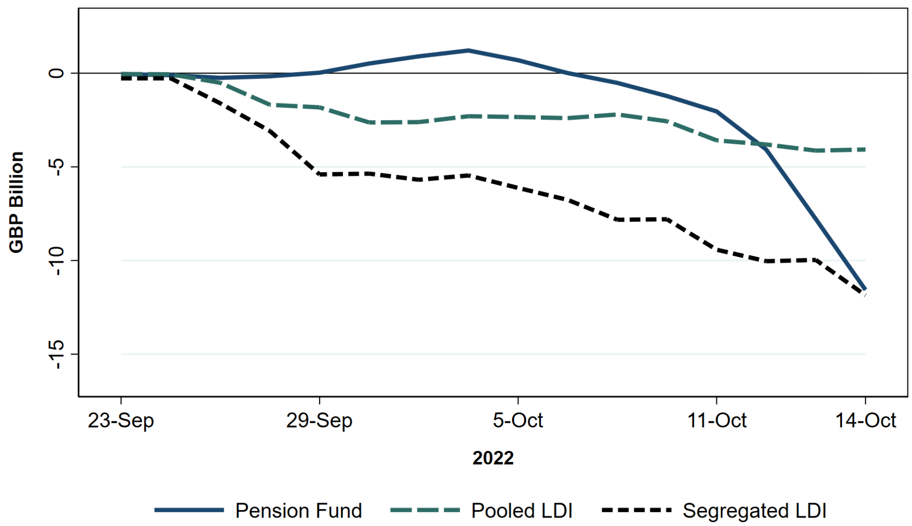
NOTE. Estimated liquidity needs in USD bn. after a 100bps rise in interest rates of US life insurers from their USD Interest Rate Swap (IRS) positions. The measure corresponds to $LASH^A_{i,t}$ as defined in equation 8 in Section 3.2. Swap positions are reported in NAIC Schedule DB, and were retrieved from S&P Capital IQ Pro. The sample covers US insurers where we could consistently classify at least 70% of their trades. The sample contains 88% of all trades and 87% of the gross notional in USD IRS held by US life insurers. Details in Internet Appendix Section I.

Figure II.10 UK Bond Market Crisis: Non-Banks' Bond Trading Volumes



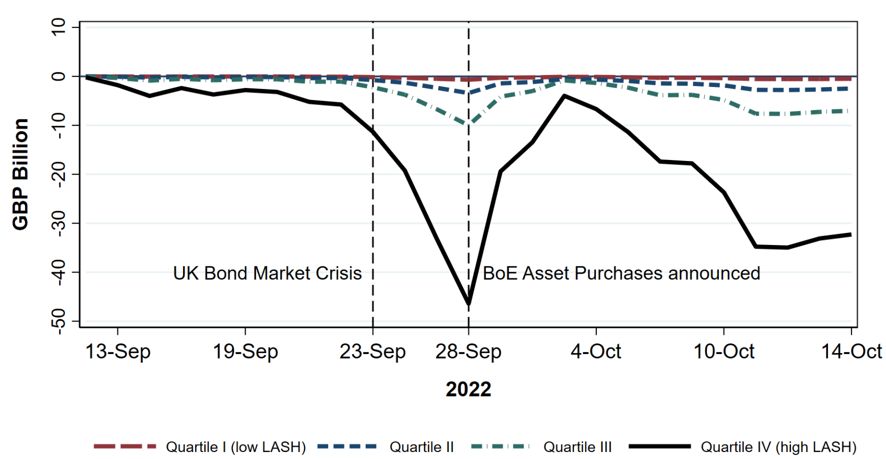
NOTE. Total net gilt trading volumes of UK non-bank financial institutions following the Mini-Budget announcement on September 23 up until the end of the BoE intervention on October 14.

Figure II.11 UK Bond Market Crisis: Pension & LDI Funds' Gilt Trading Volumes



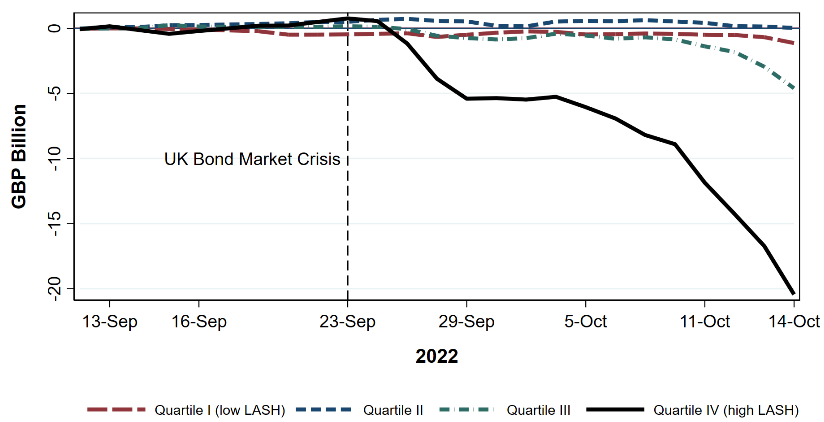
NOTE. Total net gilt trading volumes of UK pension & LDI funds' (split into pension funds, segregated LDI funds and pooled LDI funds) following the Mini-Budget announcement on September 23 up until the end of the BoE intervention on October 14.

Figure II.12 UK Bond Market Crisis: Estimated Cumulative Changes in the Value of Repo Collateral posted by Pension & LDI Funds



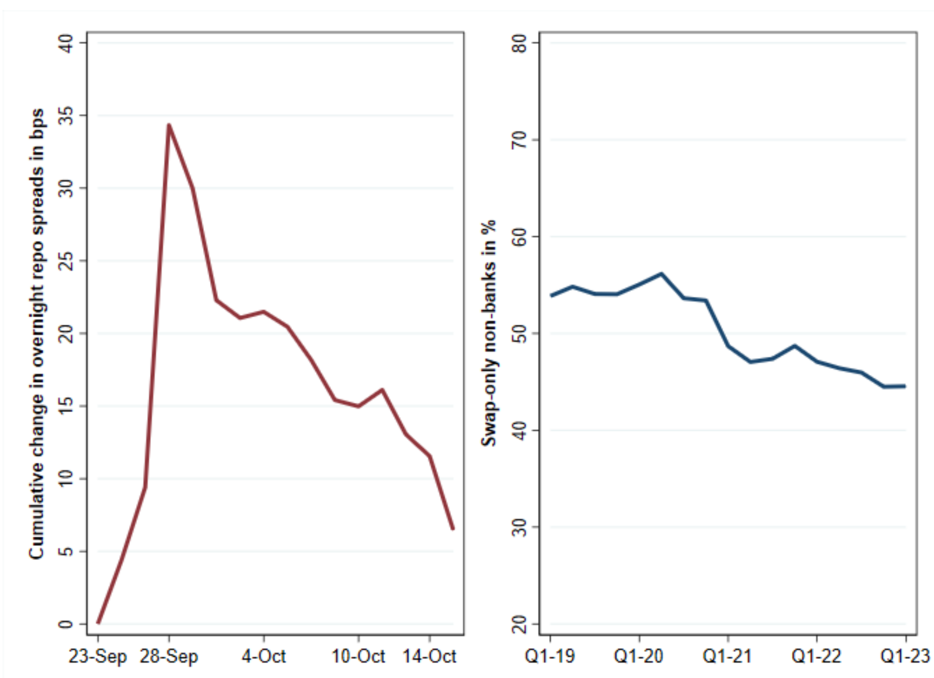
NOTE. Aggregate estimated changes in the value of repo collateral posted by UK pension and LDI funds in £bn during the 2022 UK bond market crisis, by quartile of their pre-crisis LASH risk: Quartile I captures the non-banks with the lowest pre-crisis LASH exposures, while Quartile IV captures those with the highest pre-crisis LASH exposures. Source: Sterling Money Market data collection.

Figure II.13 UK Bond Market Crisis: Pension & LDI Funds' Cumulative Gilt Trading Volumes based on pre-crisis LASH exposure



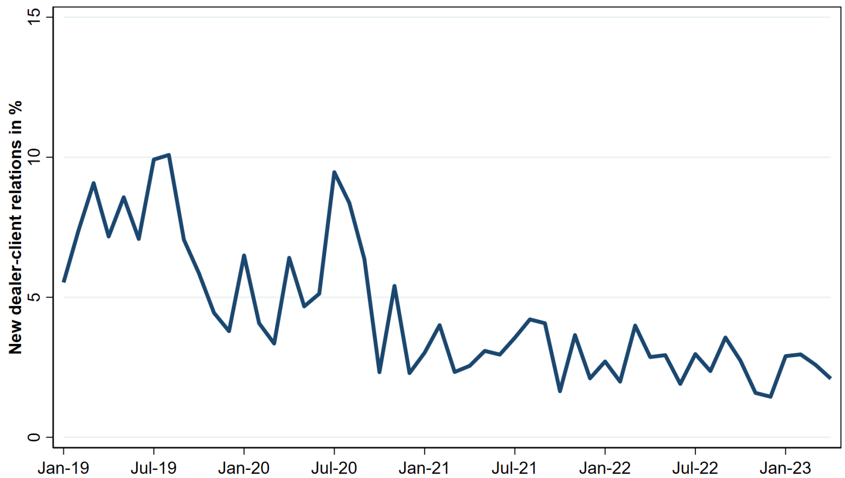
NOTE. Total net gilt trading volumes of UK pension funds and LDI funds, by quartile of their pre-crisis LASH risk: Quartile I captures the non-banks with the lowest pre-crisis LASH exposures, while Quartile IV captures those with the highest pre-crisis LASH exposures.

Figure II.14 Overnight Repo Spreads and Limited Access to Repo Market



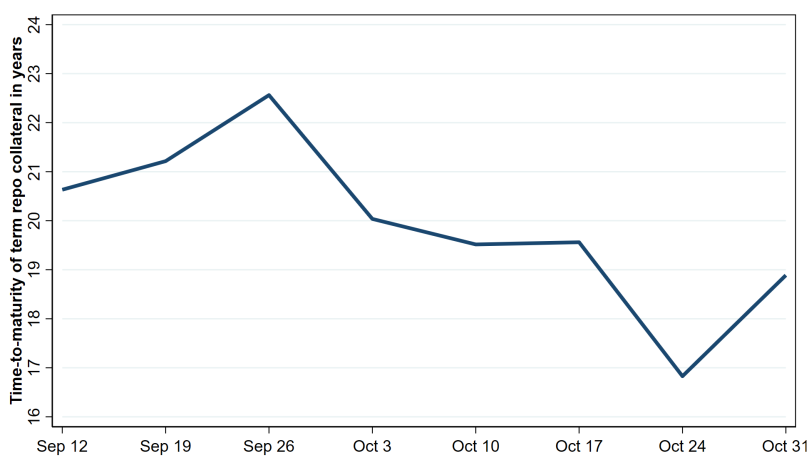
NOTE. Left Panel: Cumulative change in overnight gilt repo spreads (in bps) during the 2022 UK bond market crisis. Right Panel: Share of non-banks that only hold interest rate swaps in their portfolios, and are not borrowing or lending via the repo market, measured quarterly for the period from Q1 2019 to Q1 2023. Source: Sterling Money Market data collection & EMIR Trade Repository Data.

Figure II.15 Repo Market: New Dealer-Client Relationships



NOTE. Average monthly share of trades in the repo market that constitute a newly formed relation between a dealer and a non-bank client. Source: Sterling Money Market data collection.

Figure II.16 UK Bond Market Crisis: Average Time-to-maturity of Gilt Repo Collateral



NOTE. Weekly average of the time-to-maturity of gilt collateral in term repo trades of pension funds and LDI funds during the 2022 UK bond market crisis. Source: Sterling Money Market data collection.