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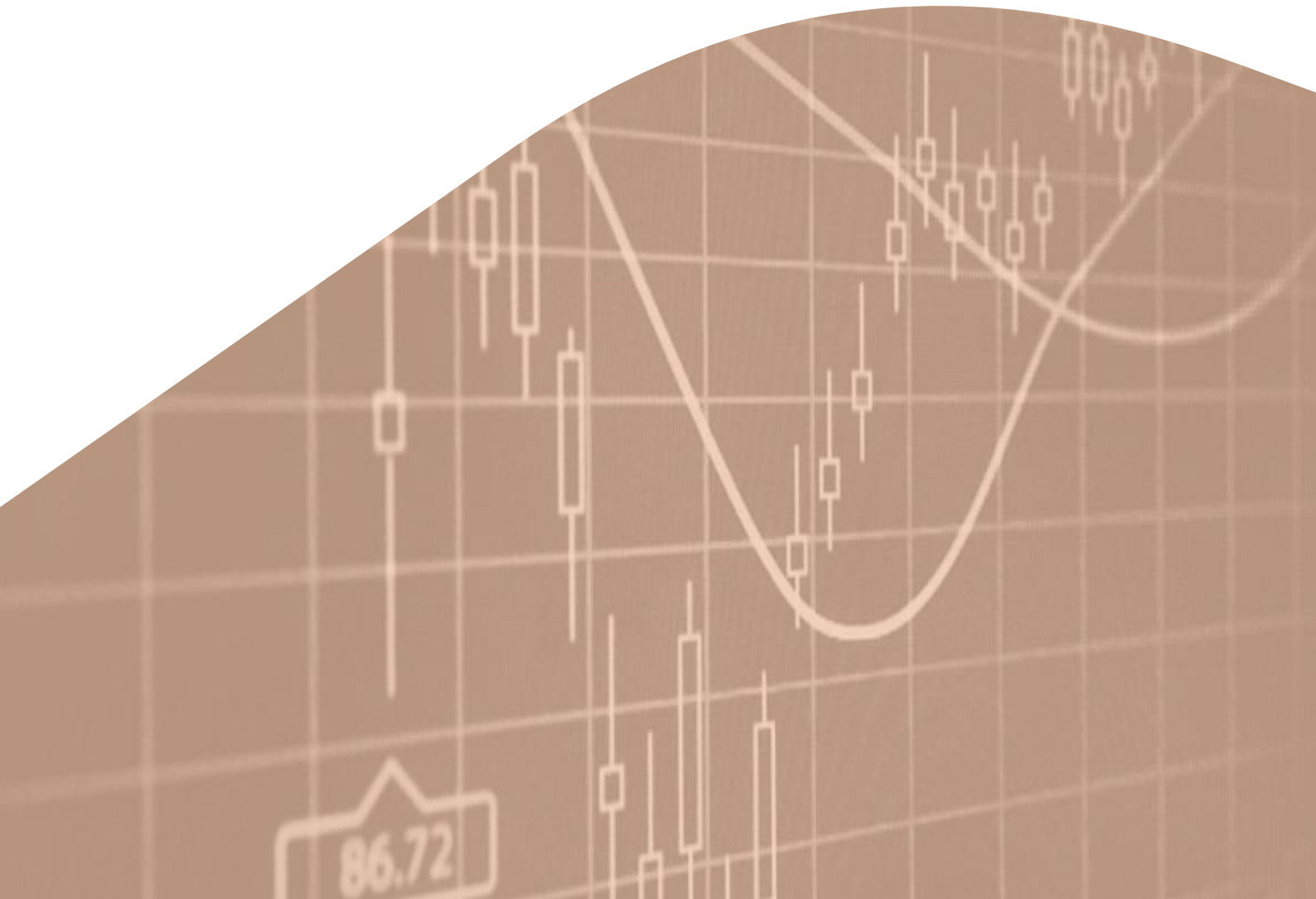
ESMA TRV Risk Analysis

Financial Stability

LDI funds - recent developments and methods for liquidity stress testing



ESMA Report on Trends, Risks and Vulnerabilities Risk Analysis

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Financial Stability

LDI funds - recent developments and methods for liquidity stress testing

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Summary

EU-domiciled GBP funds pursuing liability driven investment strategies (LDI) faced severe stress in September 2022. The use of leverage through repo borrowing and interest rate derivatives, coupled with concentrated exposures to segments of the UK sovereign bond market exposed them to large, unexpected interest rate shocks.

The surge in yields during the mini-budget crisis at the time triggered large mark-to-market losses on portfolio holdings and derivative positions, and a decline in the value of collateral posted for repo borrowing. These losses led to high liquidity demands for LDI funds triggering forced sales of gilts, increasing price pressures on the UK sovereign bond market.

Following that episode, national competent authorities (NCAs) took measures to increase the resilience of GBP LDI funds by imposing that funds should be able to withstand a 300 basis-point interest rate shock.

The analytical focus of this article is twofold. First, we review the risks associated with LDI funds business models, their use of leverage and monitor their resilience to liquidity stress over time. Second, we explicitly incorporate liquidity risks into a fund stress testing framework. This enhanced fund stress testing approach shows how a stress testing framework can help ESMA and NCAs identify risks within cohorts of funds.

In terms of risk monitoring, we find that the ability of funds to meet liquidity demands has improved compared to September 2022 after leverage-related measures under Article 25 of AIFMD were implemented. This has been driven by a reduction in leveraged exposures and a decline in the size of the segment, with the NAV amounting to EUR 113bn end-2024 compared with EUR 130bn at the time of the crisis. However, results for end-2024 show that a subset of funds might still face challenges in meeting liquidity demands in case of a large interest rate shock.

ESMA and NCAs continue to actively monitor GBP LDI funds as a potential high-risk area within the Alternative Investment Funds universe.

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Introduction

In September 2022, the UK mini-budget crisis triggered a surge in long-term sovereign yields which led to solvency and liquidity issues for GBP funds pursuing Liability-Driven Investment strategies (LDI). These funds, which are mostly domiciled in the EU, are used by UK pension funds to reduce the maturity and return mismatches between their assets and their liabilities.

While the unfolding of the LDI crisis has been covered in detail elsewhere[2], this article provides an in-depth analysis of risks around LDI funds, in the context of recent macroprudential measures.

We assess the risks and vulnerabilities of EU GBP LDI funds, and we review their business model and the corresponding risks those funds might face. We then document how the stress observed in September 2022 resulted in liquidity issues related to margin and collateral calls.

Following the crisis, EU National Competent Authorities (NCAs) in Ireland and Luxembourg implemented leverage-related measures under Article 25 of AIFMD. These measures require LDI funds to be able to withstand at least a 300-basis points increase in interest rates. In that context, we use a stress test approach to assess the resilience of LDI funds. We compare estimated liquidity demands stemming from collateral calls on repo borrowing and margin calls from interest rate derivatives to holdings of highly liquid assets.

Finally, we document how the resilience of LDI funds has evolved and what were the main drivers behind its changes since 2022. While the resilience of the GBP LDI sector has improved, their business model makes them vulnerable to sudden changes in yields, requiring active monitoring by ESMA and NCAs.

Risks and vulnerabilities related to Liability-Driven Investment strategies

Overview of GBP LDI business model

UK defined-benefits pension funds provide guaranteed returns to future pensioners. To do so, pension funds must invest in long-dated assets (to match the duration of their future payment to pensioners) and ensure that the returns on those assets are high enough to meet the guaranteed returns. In that context, some small UK Pension schemes use pooled funds pursuing LDI strategies, rather than investing directly into long-term assets, as pooled LDI funds offer a more cost-effective hedging solution (Chen and Kemp, 2023). Those GBP LDI funds are typically domiciled in Ireland and Luxembourg, two global asset management centres[3].

Reducing the duration mismatch. Schematically, a pension fund seeking an LDI exposure would typically purchase shares of LDI funds, and the LDI funds would be used to reduce the duration mismatch between pension fund liabilities (long-term guaranteed returns) and assets. The LDI fund targets a long duration by investing directly in long-dated sovereign bonds (including inflation-linked bonds)[4]. However, given the limited supply of long-term sovereign bonds, transaction costs and other factors, LDI funds also increase their duration synthetically, using long-term interest rate derivatives (IRDs)[5]. LDI funds get exposed to higher rates as they receive a fixed rate and pay a floating rate, thereby reducing the duration mismatch for the pension fund.

Reducing the return mismatch. Given the low returns on sovereign debt, LDI funds use leverage to reduce the mismatch between the return on assets and the guaranteed returns promised to future pensioners. Funds can obtain

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2 See for example ESMA (2023a) and ESRB (2023).

3 A large portion of the GBP LDI fund industry is located in Ireland as a result of a combination of factors. This includes use of the English language, a common law system that may appeal particularly to UK decision-makers or those wishing to engage with the UK financial system, and a favourable tax environment. See Lane and Moloney (2018) and Cima et al. (2019) for further details.

4 LDI funds also use inflation swaps to hedge their portfolio against inflation risk, since guaranteed returns are also tied to inflation, see Barria and Pinter (2023).

5 For further details on the use of swaps see Pinter (2023).

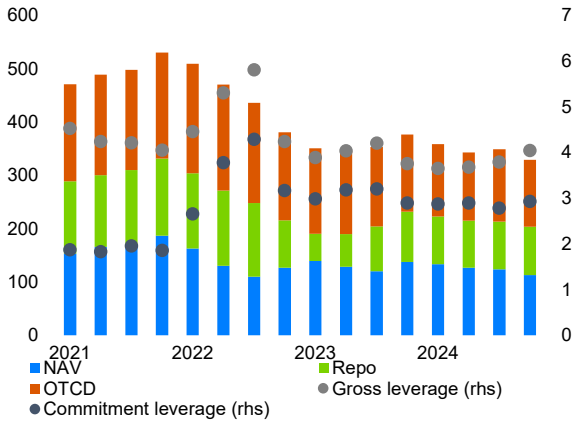
leverage through repo borrowing, by pledging some of their long-dated bonds as collateral and using the cash to purchase similar or higher-yielding assets (ESRB, 2023). Leverage can also be obtained using derivatives (synthetic leverage), as the exposure of LDI funds to interest rates is a fraction of the initial margin posted.

Risks and Vulnerabilities

We follow the approach set up by the Financial Stability Board to measure risks related to leverage in Non-Bank Financial Intermediation (FSB, 2024). The analysis relies on leverage measures, complemented by indicators of concentration risks and metrics related to liquidity preparedness. We use a sample of 335 EU-domiciled GBP LDI funds, identified using the name of the funds and information from supervisory authorities[6].

Leverage. The use of leverage is visible in entity-level data (AIFMD), where funds report a range of information, and in activity-level data (SFTR for repo and EMIR for derivatives). Chart 1 shows the evolution of EU GBP LDI funds leverage over 2021-2024. Mid-2022 (before the mini-budget crisis), the net asset value (NAV) of GBP LDI funds amounted to around EUR 130bn, while their assets under management (AuM), which measure gross exposures, amounted to EUR 690bn, resulting in a gross leverage of around 5 times the NAV[7]. The net leverage of LDI funds, measured through the commitment method — which accounts for netting and hedging arrangements — reached 3.8 times the NAV over that period. Net leverage stemmed from repo borrowing for around EUR 140bn and synthetic leverage through derivatives for EUR 178bn. Since then, repo and derivatives exposures have shrunk.

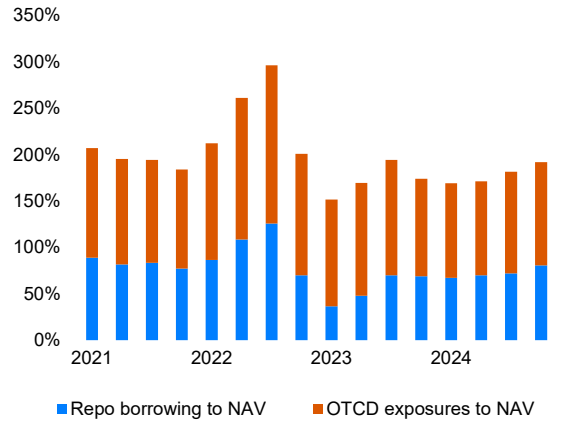
Chart 1
LDI exposures
Increase in leverage mid-2022



Note: EU GBP LDI funds net asset value and borrowing through repo and borrowing embedded in OTC derivatives in EUR bn, leverage in multiples of NAV.
Sources:AIFMD, ESMA.

Chart 2 shows a decomposition of the source of leverage from repo and derivatives. Both sources of leverage increased substantially in 2022, reaching close to 300% of NAV, before receding. As of end-2024, the ratio stood at around 190% of NAV, comparable to levels reached end- 2021.

Chart 2
LDI leverage-related exposures
Sharp rise mid-2022



Note: EU GBP LDI funds repo borrowing and OTCD exposures to NAV in %.
Sources:AIFMD, ESMA.

[6] The sample includes all GBP LDI funds that are subject to AIFMD Art. 25 measures.

[7] In AIFMD, funds have to report a gross leverage measure that excludes cash positions in the base currency of the fund. Here we calculate gross leverage including cash positions based on exposure data reported by AIFs. Since cash positions are small compared to other exposures, the AuM to NAV ratio is very close to the gross leverage directly reported by AIFs.

Concentration of exposures and portfolio similarity. GBP LDI funds are subject to three different risks related to their portfolio exposures. First, their portfolio concentration is very high: in 2022Q2 UK gilts accounted for 91% of their securities exposures (185% of NAV)[8]. The lack of diversification implies that adverse price movements on gilts have a large impact on the value of portfolio holdings. Second, LDI funds have a large footprint in the gilt market and related markets (repo collateralised by gilt and interest rate derivatives)[9]. Dunne et al. (2023) report that Irish-domiciled GBP LDI funds held around 10% of UK gilts outstanding end-August 2022. In addition, since LDI holdings are skewed towards long-dated and inflation-linked bonds, their footprint is even larger in those segments, accounting for 20% of outstanding bonds[10]. Finally, LDI funds have substantial exposures to the same assets, including at instrument level. Since AIFMD does not provide granular portfolio information, we rely instead on SFTR data, where instrument-level information is available on bonds pledged as collateral by LDI funds. We measure the collateral overlap using cosine similarity at instrument level (Girardi et al., 2021).

The cosine similarity between the collateral portfolio of two LDI funds w_i and w_j, where w is the vector of portfolio weights for each fund, is defined as:

$$Cosine\ similarity_{i,j} = \frac{w_i . w_j}{\|w_i\| \|w_j\|}$$

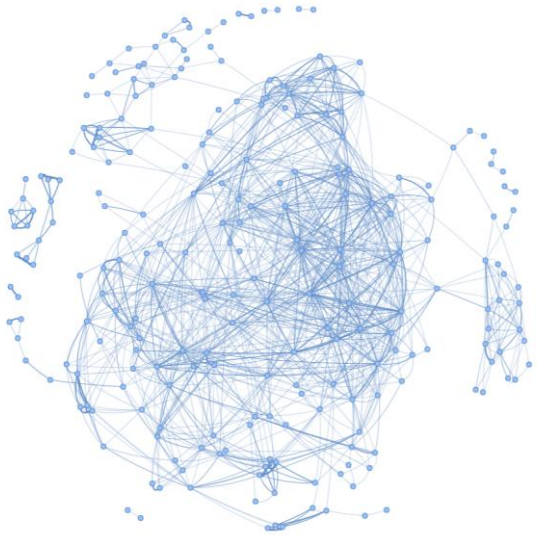
where $w_i . w_j = \sum_{k=1}^{n} w_{i,k} . w_{j,k}$

and $\|w_i\| = \sqrt{\sum_{k=1}^{n} w_{i,k}^2}$ and $\|w_j\| = \sqrt{\sum_{k=1}^{n} w_{j,k}^2}$.

The similarity measure ranges between 0 (no overlap) to 1 (perfect overlap). Chart 3 shows the portfolio overlap measures when the cosine similarity is above 0.5. It indicates that collateral overlap is very high for some funds and instruments. Large edges (representing high cosine similarity values) between nodes (LDI funds) are visible, implying that most funds post the same gilts as collateral for repo borrowing.

The combination of high portfolio concentration, high market footprint and high portfolio overlap implies that, if LDI funds were to liquidate sovereign bonds, the downward pressure on prices would be high (as LDI funds own a large share of the market) and would spread to other LDI funds (due to portfolio overlap)[11].

Chart 3
Portfolio similarity
Very high degree of common exposures



Note: The network shows bilateral cosine similarity values between LDIs (nodes). The width of the edge is related to the range of the similarity indicator. Only values above 0.5 are shown for readability. Data as of December 2023.
Sources: SFTR, ESMA.

Counterparty concentration. Another salient feature of LDI funds is that they are managed by a small number of AIFMs: the three largest managers account for 77% of the NAV. LDI funds also tend to use a small range of counterparties

[8] The high exposure to gilts is a feature of GBP LDI funds: end 2023Q4, gilt exposures accounted for 85% of securities holdings, amounting to 135% of NAV.

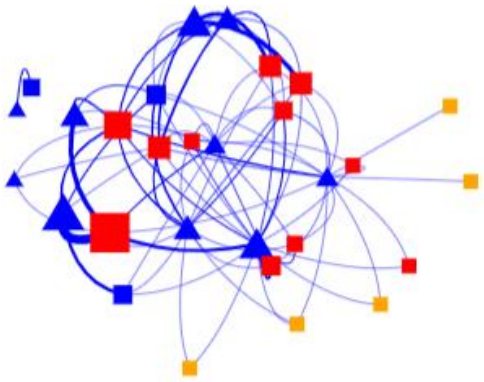
[9] The large footprint is also visible in terms of trading activity of LDI funds in the gilt market: Barria and Pinter (2023) document that the funds account for more than 25% of volumes traded and close to 50% for long-dated gilts and inflation-linked bonds. LDI funds have also a large presence in derivatives markets: they account for close to 100% of long positions on inflation swaps (Barria and Pinter, 2023) and around 50% of short positions on IRDs (pay float receive fixed rate), see Pinter and Walker (2023).

[10] 2022Q2 AIFMD data indicate sovereign holdings of EUR 248bn, and instrument-level data from SFTR shows that most of the bonds used as collateral are long-dated or inflation-linked bonds. Since gilt outstanding amounted to EUR 2.4trn over the same period, of which 53% were either index-linked or long-dated (above 15 years), we estimate a market share of LDI funds of 19% over these segments.

[11] The combination of high market footprint and high portfolio overlap is not unique to LDI funds. MMFs have similar vulnerabilities, although they are not leveraged, see ESMA (2021) for further details.

for their derivatives business, typically UK and US banks rather than EU entities (Chart 4). Such level of counterparty concentration is consistent with the central role played by UK counterparties in interest rate derivatives: ESMA (2023b) reports that notionals between EU and UK counterparties account for 59% of all IRD exposures. In the case of GBP LDI funds, the reliance on GBP assets also explains the role played by UK counterparties.

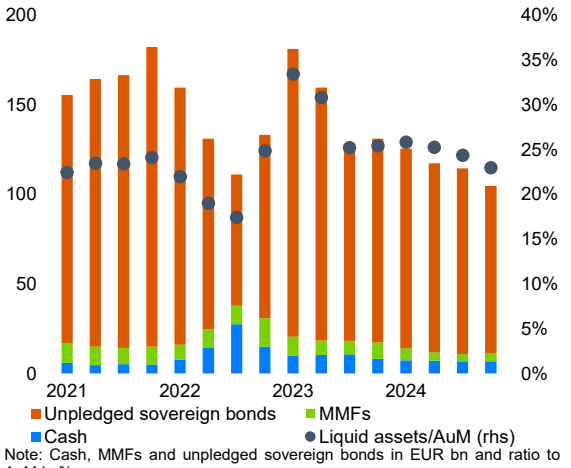
Chart 4
Counterparty exposures of LDI funds
Concentrated towards non-EU banks



Note: Network of bilateral derivatives exposures of GBP LDI funds (aggregated at manager level). The size of the node is proportional to gross notional exposures, and the thickness of the edges is proportional to bilateral notional exposures. Data as of end-2023.
Sources: EMIR, ESMA.

Liquidity preparedness. The use of leverage by LDI funds through repo borrowing and IRDs expose those funds to collateral and margins calls in case of adverse market developments. Holdings of highly liquid assets such as cash, money market fund shares or unencumbered sovereign bonds can help funds meet liquidity demands without resorting to forced sales that would amplify price shocks. Chart 5 shows a decline in the ratio of liquid assets to NAV from 24% end-2021 to less than 19% mid-2022 ahead of the mini-budget crisis. LDI funds increased subsequently their holdings of liquid assets to more than 30% in 2023H1. Since then, the share of liquid assets has declined to reach 23% of NAV end-2024.

Chart 5
Highly liquid assets
Abrupt changes in liquidity



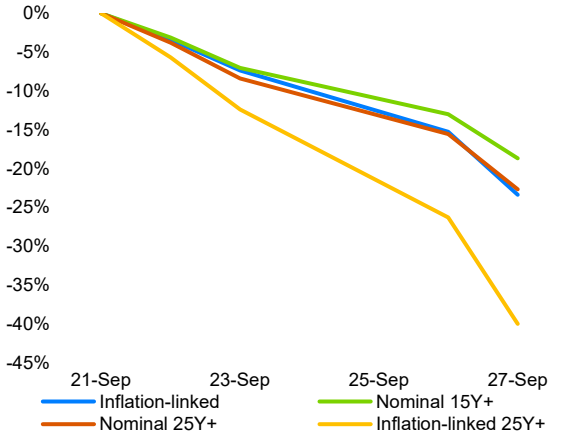
Note: Cash, MMFs and unpledged sovereign bonds in EUR bn and ratio to AuM in %
Sources:AIFMD, ESMA.

The mini-budget crisis of September 2022

The risks and vulnerabilities previously identified were put to the fore during the UK mini-budget crisis of September 2022.

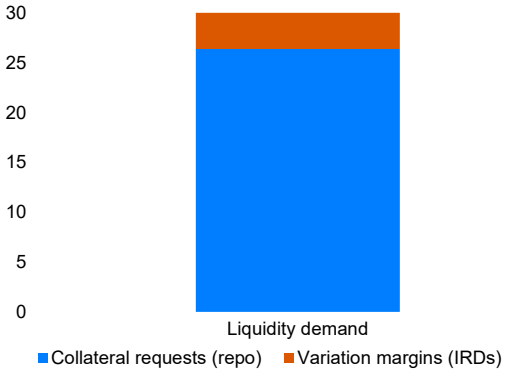
Following the announcement of the mini-budget, UK yields spiked between 22 and 29 September: the 30-year rate jumped 130 basis points over that week, an unprecedented move. The surge in yields triggered a large drop in bond prices, including for long-term bonds pledged as collateral, whose value plunged by more than 40% for some of them (Chart 6). The fall in bond prices was even larger for inflation-linked bonds, whose holdings by LDI funds account for 20% of the outstanding amounts (Pinter, 2023). Using EMIR data and industry surveys, Dunne et al. (2023) estimate that Irish-domiciled LDI funds experienced a 40% decline in NAV during the event. Relatedly, the mark-to-market value of IRDs for counterparties paying floating rates — such as LDI funds — plummeted as well, resulting in variation margins.

Chart 6
Gilt nominal and inflation-linked bonds
Collapse in market value



Note: Cumulative change in market value of UK gilt bond indices since 21 Sep. 2022, in %
Sources: ICE Bank of America, Refinitiv Datastream, ESMA.

Chart 7
Liquidity demands faced by LDI funds
High collateral calls



Note: Liquidity demand based on estimated changes in collateral value for repos and based on reported changes in market value for IRDs, in EUR bn. Changes between 22 and 27 September 2022 for collateral requests and 23 and 30 September for variation margins.
Sources: AIFMD, EMIR, SFTR. ESMA.

We estimate that liquidity demands from collateral requests and variation margins amounted to more than EUR 36bn during the last week of September (EUR 26bn from collateral calls and EUR 10bn from variation margins, Chart 7), representing more than 45% of the stressed NAV of LDI funds (assuming a 40% drop in the NAV)[12].

At the aggregate level, LDI funds had EUR 25bn in cash and MMF shares. However, the liquidity position of funds was varied, as some funds had 'excess liquidity' while others faced a liquidity shortage. Therefore, some LDI funds had to liquidate sovereign bonds to raise cash, thereby amplifying the downward price pressure on gilts (Pinter, 2023) [13]. The price impact of LDI sales was also visible in the deterioration of market liquidity measured by bid-ask spreads (ESRB, 2023), and forced sales created a negative feedback loop: sales of gilts resulted in lower bond prices, triggering further liquidity demands and additional forced sales by LDI funds. The negative effect was also amplified by the fact that most gilts held by LDI funds were concentrated on the long-term and inflation-linked segment of the UK sovereign bond market (Dunne et al., 2023) [14]. Forced deleveraging by LDI funds triggered the intervention of the Bank of England through temporary asset purchases targeted at the long end of the gilt market[15]. Such intervention allowed yields to decline and provided time for managers of LDI funds to reduce their risk profile.

[12] The stressed NAV is calculated by applying the price discount observed on pledged bonds to the NAV.

[13] LDI funds also used recapitalisation (where pension funds are requested to inject capital into the funds) to raise cash, but operational challenges made the recapitalisation process complex and, in some cases, not possible (as recapitalisation typically occurs over one week), see Chen and Kemp (2023).

[14] Using granular transaction data, Pinter et al. (2024) estimate that forced sales by LDI funds led to price declines of 10%, accounting for half of the total decline in gilt prices.

[15] See Breeden (2022).

The aftermath: Supervisory measures

Supervisory actions by NCAs

Following the stress event, the two NCAs where EU GBP LDI funds are domiciled took a range of measures to ensure the resilience of GBP LDI funds. In November 2022, the Commission de Surveillance du Secteur Financier (CSSF) and the Central Bank of Ireland (CBI) provided supervisory guidance to GBP LDI managers, by asking them to maintain an appropriate level of resilience (measured by a fund ability to withstand an interest rate shock of at least 300 to 400 basis points) and a reduced risk profile (ESMA, 2022b).

In April 2024, both NCAs imposed macroprudential measures under Article 25(3) of AIFMD. Article 25 of AIFMD gives NCAs the power to impose leverage limits or any other restrictions on AIFMs with respect to the AIFs they manage. This power was used for the first time in 2022 by the Central Bank of Ireland for commercial real estate funds (ESMA, 2022a). In the case of GBP LDI funds domiciled in Ireland and Luxembourg, both NCAs chose to impose a yield buffer requirement rather than direct limits on leverage. The measure requires GBP LDI funds to be resilient to a shock of at least 300 basis points, with the measure entering into force end-July 2024 (ESMA, 2024).

These measures can be interpreted as a combination of a solvency constraint (the fund should keep a positive NAV) and a liquidity constraint (the fund should have enough unencumbered assets to meet margin and collateral calls).

A model of yield buffers

The Article 25 measures can be modelled in a simplified set-up, focusing on repo borrowing and excluding IRDs[16]. We do not take into account the possibility for LDI funds to be recapitalised, since the focus of the model is on a short-term horizon, and that recapitalisation procedures can take place over a longer time period and be quite complex due to coordination issues around multiple pension schemes (Pinter et al. 2025)[17].

Balance sheet of the LDI. We make the following assumption: LDI funds invest in a single type of asset, with part of the portfolio pledged as collateral (A_p) in repo transactions (R), and the remainder held as unencumbered assets (A_u).

The fund's balance sheet identity is therefore:

$$A_p + A_u = NAV + R$$

Repo. Repo borrowing is related to the pledged collateral through a haircut h such that:

$$R = (1 - h)A_p.$$

Leverage. Fund leverage is defined as the ratio of total assets to NAV:

$$L = \frac{A_p + A_u}{NAV}$$

Given the balance sheet identity and the definition of repo borrowing, leverage can be expressed as the ratio of total assets to the sum of unencumbered assets and the haircut value of pledged assets:

$$L = \frac{A_p + A_u}{A_u + hA_p}$$

This implies that, when haircuts are low and a large share of assets is pledged, the fund can achieve high levels of leverage.

The change in the value of the assets following an interest rate shock Δr is denoted $\delta = \Delta r \times \gamma$, where γ is the interest rate sensitivity, such that the post-shock asset value is:

$$A_{t+1} = (1 - \delta\ )A_t$$

LDI funds are subject to two key constraints: a 'solvency' constraint and a liquidity constraint.

Solvency constraint. After an interest rate shock, the fund must maintain a positive NAV:

$$(1 - \delta)\big(A_u + A_p\big) > R = (1 - h)A_p.$$

This becomes:

[16] The focus is on repo since liquidity demands came mostly from collateral calls rather than margin calls on IRDs. Derivatives can be introduced in the model by taking into account the initial margin (which would be a fraction of the exposure, similar to the haircut in repo). The sensitivity of IRDs to interest rate shock could be captured by δ as well.

[17] The authors find that pooled LDI funds sold more gilts than other LDI structures. They interpret this finding as evidence that asset sales were used because of recapitalisation issues among pooled funds.

$$\frac{A_u + hA_p}{A_u + A_p} \geq \delta$$

Liquidity constraint. The fund must have enough unencumbered assets after the shock to cover collateral calls. Asset sales have a price impact α so that the fund recovers $(1-\alpha)A_u$ when selling assets. The liquidity constraint is:

$$(1-\alpha)(1-\delta)A_u > \delta A_p$$

This can be formulated as:

$$\frac{A_u}{A_p} \geq \frac{\delta}{(1-\alpha)(1-\delta)}$$

Unencumbered assets should be large enough to compensate for the mark-to-market loss related to the interest rate shock and the losses due to asset sales. For large interest shocks, the liquidity constraint is typically more binding than the solvency constraint[18]. The higher the share of unencumbered assets, the more resilient the fund is to interest rate shocks.

Leverage after interest rate shocks. The maximum level of leverage possible under the liquidity constraint ($A_u = 0$), after shock is equal to:

$$L^{max} = \frac{A_p}{hA_p} = \frac{1}{h}$$

The leverage after shock is entirely determined by repo haircuts. If there are no haircuts on pledged assets, there is no limit on leverage.

We can define δ^{max} as the maximum sensitivity of the LDI portfolio that is consistent with the liquidity constraint:

$$\delta^{max} = \frac{(1-\alpha)A_u}{(1-\alpha)A_u + A_p}$$

The resilience of LDI funds is an increasing function of unencumbered assets A_u and a decreasing function of the price impact α (the higher the price impact the lower the resilience) and pledged assets A_p[19]. If unencumbered assets are eligible as collateral for repo borrowing, the fund does not need to sell them, implying $\alpha = 0$ and the fund can be resilient to a higher interest rate shock[20].

Since the Article 25 measures introduced by the CBI and the CSSF relate to an interest rate shock of 300 basis points, we have $\delta = 3\% \times \gamma$.

Chart 8 shows how the resilience of LDI funds changes as a function of the price impact and the holdings of unencumbered assets. Higher resilience levels (high δ^{max} shown in lighter colours) are obtained when the price impact of sales is low and when the share of unencumbered assets is high.

Chart 8
LDI funds resilience
Role of unencumbered assets and price impact

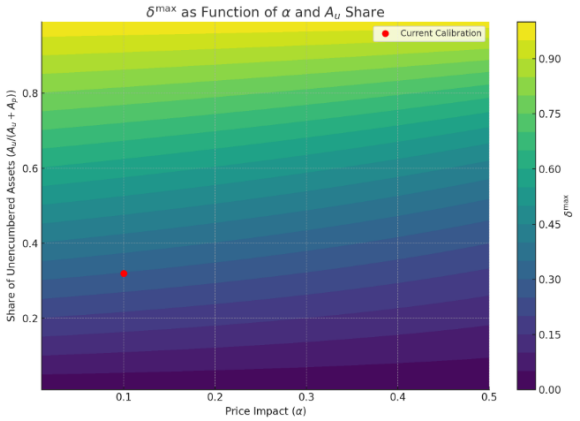


Illustration. To illustrate the balance-sheet dynamics, we assume a hypothetical LDI balance sheet with $A_p = 100$, $A_u = 47$, $h = 5\%$, $\alpha = 10\%$, yielding $R = 95$, $NAV = 52$, $\gamma = 10$ and $L = 2.8$. In this set-up the ratio of unencumbered assets to total assets is equal to 33%, yielding a value of δ^{max} equal to 30% which corresponds to the shock used for this example.

Table 1 shows the balance sheet of the LDI fund over the horizon of the shock. The interest rate shock leads to a decline in assets, triggering a collateral call of 30. The fund sells unencumbered assets worth 33 to obtain 30, given the price

[18] The solvency constraint is more binding than the liquidity constraint only when haircuts are large, price discounts and interest rate shocks are small. Formally, when we have $A_p \geq \frac{\delta}{(1-\alpha)(\delta-h)}$, the solvency constraint is more binding.

[19] The model can be extended by introducing a price impact function that depends on volumes sold. In this more complex set-up, the relationship between δ^{max} and A_u might no longer be monotonous depending on the steepness of the price impact.

[20] If there is no price impact (unencumbered assets can be posted to meet collateral calls) and no haircut then the solvency and liquidity constraints are equal.

discount. At the end of the period, the level of unencumbered assets drops to zero, resulting in a leverage of 20.

Table 1
Evolution of the LDI balance sheet

Variable	Initial values	After shock	Final values
Pledged assets (A_p)	100	70	100
Unencumbered assets (A_u)	47	33	0
Repo borrowing (R)	95	95	95
Net asset value (NAV)	52	8.3	5
Leverage (L)	2.8	12.4	20

Key takeaways. The simple model yields a range of insights.

- First, the liquidity requirement is generally the binding constraint for the fund, and it depends on the initial composition of the balance sheet of the fund. Unencumbered assets should be high enough to cover mark-to-market losses and liquidation costs to meet collateral calls. However, if unencumbered assets can be pledged as collateral for repo borrowing LDI funds do not face liquidation losses.
- Second, the resilience of LDI funds is entirely determined by the composition of their balance sheets and the price impact of asset sales and can be directly quantified. Finally, the maximum leverage of the fund when the liquidity constraint is binding is equal to the inverse of the haircut on pledged collateral.

The Article 25 measures can be interpreted as a reverse stress test: GBP LDI funds should be able to withstand at least a 300-bps increase in interest rates. One natural way to assess LDI resilience is to use a liquidity stress testing framework to estimate the ability of individual funds to meet liquidity demands related to collateral and margin calls. This is the objective of the next section.

Stress testing GBP LDI funds

The mini-budget crisis of September 2022 and the follow-up measures taken by NCAs under Article 25 emphasize the importance of ensuring the resilience of LDI funds to interest rate shocks. In that context, pricing tools can be used to assess potential collateral and margin calls related to interest rate shocks.

Scenario design

We assume a parallel shift of the GBP yield curve and the risk-free rate of 300 basis points[21]. This shock corresponds to the parameter of the yield buffer requirement set out by NCAs for GBP LDI funds. In addition, we consider alternative scenarios to assess how LDI funds resilience evolves according to the intensity of interest rate shocks. We apply the scenario to all GBP LDI funds in our sample over three different periods: Mid-September 2022 (ahead of the mini-budget crisis), end-2023 and end-2024 after the implementation of AIFMD Article 25 restrictions[22].

Impact of interest rate shocks on bonds and repo collateral

To assess the impact of the shock on bonds held and pledged by LDI funds, we need to estimate the change in the market value of those bonds for each fund. We collect AIFMD data on long positions on sovereign bonds which are then split into encumbered assets (based on collateral information from SFTR) and unencumbered assets. The impact of an interest rate shock Δr on the price of a bond P is given by:

$$\frac{\Delta P}{P} \approx -D\Delta r + \frac{1}{2}C(\Delta r)^2$$

where D is the duration of the bond and C is its convexity.

[21] Bouveret et al. (2025) follow a similar approach to assess the sensitivity of leveraged AIFs to changes in interest rates. However, they use an approximation method based on changes in the yield to maturity instead of a full repricing of IRDs as done in this article.

[22] For the mid-September 2022 stress test, we use EMIR and SFTR data as of September and AIFMD data as of June 2022. We choose to use 2022Q2 AIFMD data rather than 2022Q3 because the later refer to end-September values, i.e. after the mini-budget crisis. Using different periods might introduce some bias in the analysis. For illustration, repo borrowing peaked at EUR 154bn in June 2022, compared with EUR 135bn in September, hence using June data would overstate the liquidity shortfall by LDI funds in September.

We use SFTR data to identify the list of individual instruments pledged as collateral, and we retrieve information on bond duration and convexity for each instrument using commercial data sources. We apply a similar price shock to unpledged bonds[23]. We focus on gross borrowing by LDI funds and therefore do not account for repo lending performed by LDI funds, due to data issues in regulatory datasets (Textbox 1)[24].

Textbox 1

Data issues for stress testing

Stress testing requires data on sources of leverage and on liquid assets. One challenge is that some funds report very different values for repo borrowing in AIFMD than what they report under SFTR as gross or net borrowing, as shown in the table below.

Variable	2022	2023	2024
Repo borrowing (AIFMD)	141	95	91
Gross repo borrowing (SFTR)	136	87	81
Net repo borrowing (SFTR)	111	70	75

Sources: AIFMD, SFTR

Another challenge relates to the reporting of unencumbered assets. Some funds report long sovereign holdings in AIFMD which are lower than total sovereign bond collateral pledged in SFTR. In addition, many funds do not report any information on initial margins in EMIR despite their use of derivatives.

Looking forward, further details on the composition of assets, including information on pledged amounts by asset classes by type of activity (derivatives and securities financing transactions) would be warranted. Ongoing work on integrated reporting for funds and data quality work should support stress testing work.

Impact of interest rate shocks on interest rate derivatives

Estimating changes in the market value of IRDs following an interest rate shock is complex due to the characteristics of the derivatives. We develop a pricing tool that allows for the full repricing of derivatives after a shock (Textbox 2). The margin calls are calculated as the difference between the market value of the derivatives after the shock PV_{stress} and before the shock PV_0:

$$Margin\ calls = PV_{stress} - PV_0$$

We use EMIR data to retrieve the characteristics of each interest rate derivative position and perform some data cleaning procedures to collect the necessary inputs for valuation (Textbox 3). Our sample of IRDs cover around 85,000 positions across the three reference dates, for gross notional amounts ranging from EUR 100bn in 2022, to EUR 88bn in 2023 and 78bn in 2024, covering around 60% of LDI derivatives exposures[25]. The discount rates are obtained from commercial data sources[26].

[23] This assumes that unpledged bonds have the same characteristics as pledged bonds. For LDI funds that did not use repo borrowing, we apply a shock equal to the average price shocks estimated on pledged bonds (around 27% across the three periods).

[24] Overall gross borrowing amounted to EUR 136bn in September 2022 and net borrowing to EUR 110bn. Over the three periods, net borrowing amount to around 85% of gross borrowing. Our approach is hence more conservative.

[25] Since we restrict our analysis to interest rate shocks, we do not model derivatives whose underlying is not an interest rate.

[26] For further details on the implementation of the pricing tool, see Bouveret and Leclerc (2025).

Textbox 2

Pricing tool for IRDs

A typical interest rate swap is a financial contract where one counterparty agrees to pay a floating rate to another counterparty who commits to pay a fixed rate in return over the maturity of the contract.

Below, we take the point of view of the buyer who wants to secure fixed cash flows over a long time horizon T, like LDI funds. The buyer receives fixed cash flows and pays a floating rate in return. For the fixed leg, the future cash flows are defined as the sum of the present value of the fixed payments, equal to the agreed fixed rate r multiplied by the notional of the contract N discounted by a risk-free rate (the discount factor, noted δ. For the floating leg, the cash flows are equal to the future floating rate f (derived from the forward curve) multiplied by the notional and the discount factor. The value of the swap, from a buyer point's of view, is given by the value of the fixed leg (cash inflows) less the value of the floating leg (cash outflows):

$$PV = \underbrace{\sum_{t=0}^{T} rN\delta_t}_{fixed\ leg} - \underbrace{\sum_{t=0}^{T} f_t N\delta_t}_{floating\ leg}$$

We use Overnight Index Swaps (OIS) as risk-free rates for the discount factor. For pound-denominated assets we take the swaps on the Sterling Overnight Index Average (SONIA) as the risk-free rate s_t and we calculate the discount factor based on a continuously compounded rate:

$$\delta_t = e^{-s_t}$$

The forward rate f_t between two periods t_1 and t_2 is equal to:

$$f_t = \frac{\delta_{t_1}^{\frac{1}{(t_2-t_1)}}}{\delta_{t_2}} - 1$$

The discount factor curve depends on the maturity dates of the instrument used as benchmark for the risk-free rate. However, the future cash flows of the fixed and floating legs are not necessarily scheduled on the same dates. Therefore, the relevant discount factor curve needs to be interpolated to obtain a vector of the discount factors for each cash flow date. We use cubic splines to interpolate the curve between each observation.

Stress test. The scenario includes a shock to the discount factor, which affects both the fixed and floating leg, and a shock to forward rates which affects the floating leg. We assume a parallel shift for both the yield and the forward curves.

Textbox 3

EMIR data cleaning and implementation of the pricing tool

Data quality. Despite joint ESMA and NCAs efforts, data quality issues might arise in EMIR data, including imperfect reporting of the floating rate of the swap or missing data. Hence, we have made some assumptions in order to harmonise the data and increase its usability. We have implemented the following rules:

- **Ambiguous benchmark rate for floating rate payment.** The following strings are replaced by "SONIA": GBP-SONIA-COMPOUND, SONIO/N Index'. For other floating rate references, we use an enhanced Ratcliff-Obershelp algorithm (Ratcliff and Metzener, 1988) to compare them to SONIA, relying on the difflib library in python. If they are deemed close enough they are replaced by "SONIA".
- **Missing reference period of the floating rate.** Since the reference period for SONIA is a day, other misreported values are replaced by "day".
- **Missing day-count convention.** If the day count convention is not reported, by default we assume it is Actual/365.

Implementation. A dedicated python library has been developed to price interest swap derivative contracts. It implements the methodology and rules described above. The library gives a valuation to the floating and the fixed legs separately, and then uses the two values to obtain the value of the contract depending on whether the report has been sent by the buyer or by the seller. The library relies on discount and OIS curves retrieved from Eikon (Reuters). The library is used to shock the contracts by shifting the discount curves and the floating rate upwards or downwards.

Model validation. For each interest rate swap, the valuation obtained from the model was compared to the valuation reported in EMIR. For the majority of the swaps (63% of the contracts), the valuation difference was within 5%, and the median of the price difference is 3% (EUR 8,618). Pricing errors might be related to erroneous inputs or erroneous reported contract values in EMIR, as well as adjustments to the fair value of derivatives contracts made by counterparties to cover funding, credit risk and regulatory costs not modelled in the pricing tool (see Bianchi et al., 2024). In addition, since the model is used to reprice swaps after shocks, what matters most is the change in values rather than the levels.

Liquidity measures

We compare the liquidity demands related to collateral and margin calls to the liquidity available to LDI funds. We do not consider the possibility for LDI funds to be recapitalised by investors, since we do not have details about the operational set-up. In addition, during the 2022 crisis, recapitalisation procedures over a very

short time frame proved challenging. We define highly liquid assets as cash, MMF shares and unpledged sovereign bonds[27]. However, AIFMD data do not provide details on pledged and unpledged bonds. We assume that initial margins are paid using sovereign bonds, since EMIR data do not provide the breakdown of the assets used to post initial margins.

Therefore, we estimate unpledged bonds A_u by subtracting from long bonds holdings A, the bonds used as collateral for repo A_p (identified using SFTR) and the amount of initial margins A_{IM} reported in EMIR[28]:

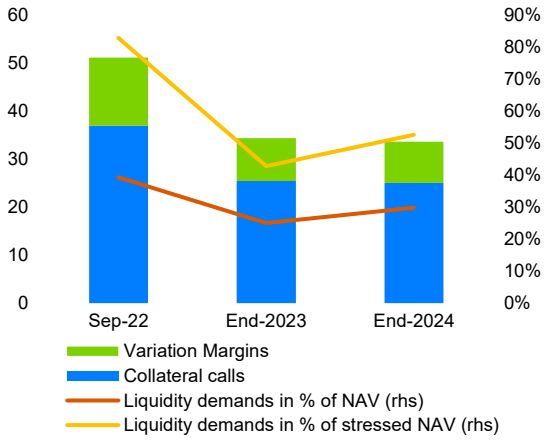
$$A_u = A - A_p - A_{IM}$$

Since unpledged bonds are also affected by the interest rate shock, we apply the same price discount as the one used for pledged bonds. Relatedly, we compute a revised NAV that considers those mark-to-market losses on bond holdings[29].

Results

Liquidity demands stem mostly from collateral calls on repo borrowing rather than margin calls on IRDs. Pledged collateral consists mostly of long-dated bonds which have a high sensitivity to changes in yields: the 300-bps shock triggers an average decline of 27% of the value of the pledged collateral. In contrast, variation margins amount to 7% of IRDs' exposures. This difference reflects a lower sensitivity of the market value of IRDs to change in yields, which is not captured by gross notional values. In monetary terms, liquidity demands amount to EUR 51bn in September 2022 (EUR 37bn for collateral calls and EUR 14bn for variation margins), before declining in 2023 to EUR 34bn (EUR 25bn for collateral calls and EUR 9bn for margins) and to EUR 34bn in 2024 (EUR 25bn for collateral calls and EUR 9bn for margins) as LDI funds reduced their repo borrowing and their use of IRDs (Chart 9). In relative terms, liquidity demands reached 83% of the post-shock NAV in September 2022 (considering mark-to-market losses on unpledged bonds) or 39% of the pre-shock NAV. In 2023 and 2024, liquidity demands accounted for around 45% of the post-shock NAV (27% of the pre-shock NAV).

Chart 9
Liquidity demands
Large collateral calls



Note: Liquidity demands in EUR bn and in % of NAV.
Sources: AIFMD, EMIR, ESMA.

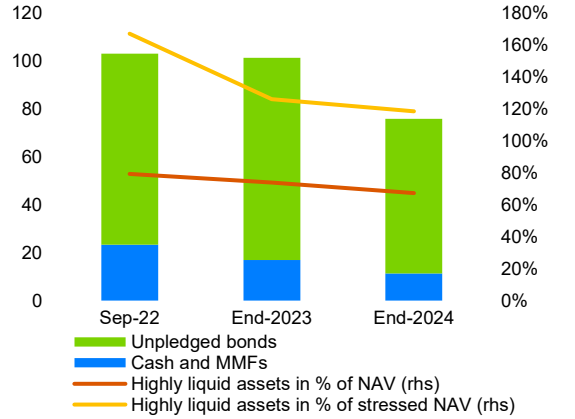
Highly liquid assets. Mid-2022, LDI funds held around EUR 137bn in highly liquid assets, mostly unpledged bonds (EUR 114bn). Once the valuation changes are considered, highly liquid assets amounted to EUR 103bn (Chart 10), accounting for 80% of their aggregate NAV (170% of the stressed NAV). Those holdings declined afterwards to reach around 70% of the NAV (110% of the post-shock NAV) end-2024.

[27] Other highly liquid assets could be mobilised by the funds to meet liquidity demands. However, those assets are a small part of LDI funds securities exposures: gilts, cash and MMFs account for 80% of securities exposures on average, with a median of 98% over 2022-2024.

[28] Data on initial margins for LDI funds in our sample are scarce in EMIR, possibly due to reporting issues, as many funds do not report initial margins. Data for 2022 data point to initial margins of EUR 2.7bn compared with EUR 198bn in net notional exposures (less than 2% of gross exposures) and data for 2023 and 2024 point to a margin ratio of around 1.2% (initial margins represent 1.2% of net notional exposures).

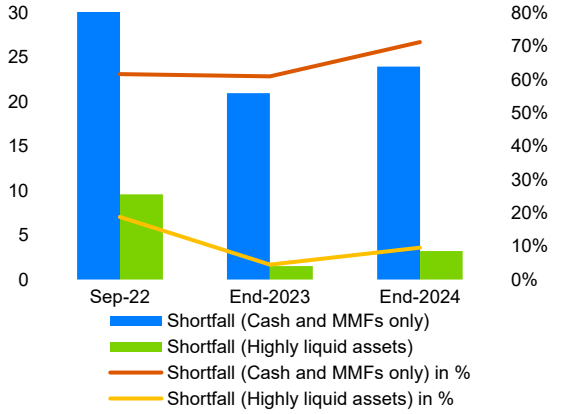
[29] For some funds this can result in negative NAV.

Chart 10
Highly liquid assets
Decline related to deleveraging



Note: Highly liquid assets in EUR bn and in % of NAV.
Sources: AIFMD, EMIR, ESMA.

Chart 11
Liquidity needs
Large gaps when considering cash only



Note: Liquidity shortfall in EUR bn and in % of liquidity demands (rhs).
Sources: AIFMD, EMIR, ESMA.

Liquidity shortfall. We define the liquidity shortfall as the difference between liquidity demands and highly liquid assets at fund level. Aggregate values might overstate the liquidity preparedness of LDI funds, as the 'excess liquidity' of some funds might compensate liquidity shortfalls for other funds. In September 2022, the liquidity shortfall amounted to EUR 31bn (61% of liquidity demands), when considering only cash and MMFs as liquid assets (Chart 11). The shortfall declined to EUR 9bn (19% of liquidity demands), as of September 2022, when also including unpledged bonds. In that case, LDI funds would need to sell EUR 22bn of gilts, which is more than the daily average trading volumes of all UK sovereign bonds[30], unless those bonds could be directly mobilised as collateral, avoiding forced sales. Overall, there are 187 LDI funds that would face a shortfall when considering only cash and MMFs, and 59 funds when including unpledged sovereign bonds.

The liquidity shortfall is lower in 2023 at EUR 21bn, but still persistent when considering only cash and MMF shares (208 funds would have a shortfall). When unpledged bonds are included, the shortfall declines to less than EUR 2bn across 19 funds. If the bonds would need to be sold to raise cash, the volumes of sales would remain very high at EUR 19bn. However, after the mini-budget crisis, many LDI funds have modified their credit support annexes (CSAs) to allow for a broader pool of collateral to be eligible. These changes allow funds to post additional bonds as collateral without needing to sell them, thereby reducing the price pressure on the sovereign bond market.

Estimated liquidity shortfalls increased slightly in 2024 to EUR 24bn (EUR 3bn when including bonds) with 231 funds facing a shortfall when considering cash and MMFs (31 funds when including unpledged bonds).

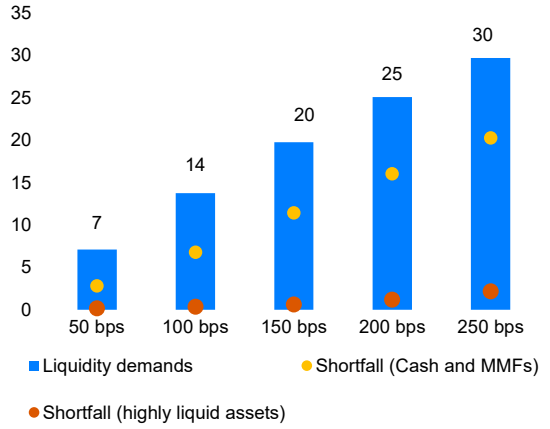
Reverse stress tests. We analyse shocks to interest rates ranging from 50 bps up to 250 bps, using 50 bps increments, in line with recent work done in the UK[31]. Chart 12 shows the evolution of liquidity demands and liquidity shortfalls for these series of shocks. For interest rate shocks up to 150 basis points, the liquidity shortfall (using highly liquid assets) would be less than EUR 1bn for GBP LDI funds. In terms of liquidity demands,

[30] According to the Bank of England letter to the Chair of the Treasury Committee, 5 October 2022, average daily trading volumes on UK sovereign bonds were around GBP 12 billion (around EUR 14bn).

[31] In its July 2025 Financial Stability Report, the Bank of England used interest rate shocks ranging from 25 bps to 100 bps and applied the shocks to end-April 2025 data, see BoE (2025).

our estimates are commensurate with the work done by the Bank of England: for a 100-bps shock, liquidity demands faced by GBP LDI fund would amount to EUR 13.8bn in our calculations, compared with EUR 10.1bn for Bank of England.

Chart 12
Reverse stress tests
Increasing liquidity demands



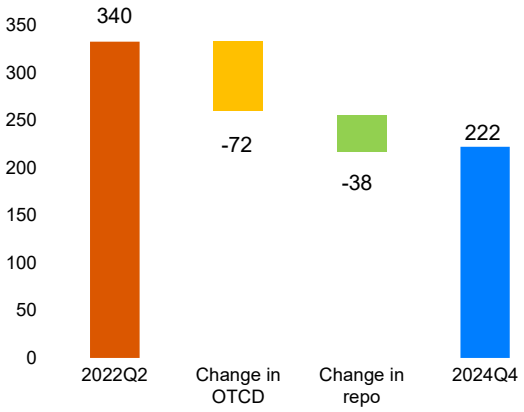
Note: Liquidity demands and liquidity shortfalls in EUR bn.
Sources: AIFMD, EMIR, SFTR, ESMA.

What drove the change in LDI resilience?

Stress test results indicate that the resilience of LDI funds has changed over time. Such changes can come from different liquidity demands and/or changes in holdings of highly liquid assets. Regarding liquidity demands, any reduction is tied to (i) a decline in (leveraged) exposures, or (ii) lower interest rate sensitivity.

Decline in LDI exposures. Overall, LDI funds reduced their exposures on an absolute and relative basis. Between mid-2022 and end-2024, the ratio of repo borrowing and OTC derivatives exposures to NAV declined from 256% to 200%. Repo borrowing declined by EUR 72bn (Chart 13), leading to a 28-percentage points decline of the ratio of repo borrowing to NAV (from 101% of NAV to 85%). Relatedly, OTC derivative exposures declined by 36% in absolute terms (from EUR 198bn to EUR 126bn) and by 41 percentage points in terms of NAV (from 152% to 111%).

Chart 13
LDI fund exposure
Broad-based deleveraging

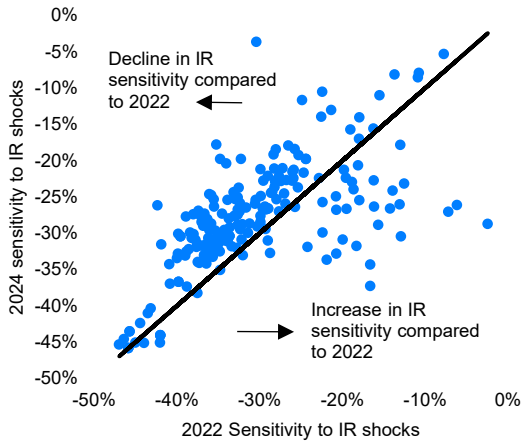


Note: GBP LDI exposures to OTCD and repo in EUR bn.
Sources: AIFMD, ESMA.

The sensitivity to interest rate shocks has slightly declined for most funds. Looking at fund-level results, the sensitivity of bond holdings to interest rate shocks has declined over time. Chart 14 compares the impact of a large interest rate shock on collateral values in 2022 and in 2024. Most funds have reduced their interest rate sensitivity, as shown by points above the 45-degree line (also reflecting the decline in duration of bonds over time), but others have increased their exposures to interest rates, as shown by the points below the 45-degree line. The median sensitivity to a 300bps shock has moved from 32% in 2022 to 27% in 2024[32].

[32] For IRDs, the sensitivity remained broadly stable at around 8% for a 300-bps shock. Variation margins amounted to 8% notionals in 2022, 7% in 2023 and 9% in 2024.

Chart 14
Repo collateral sensitivity to interest rate shocks
No large changes to rate shocks since 2022



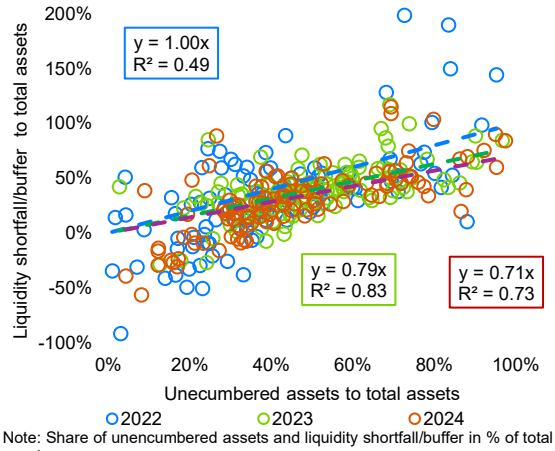
Note: Impact of 300 bps interest rate shock on collateral values in %.
Sources: SFTR, ESMA.

Holdings of highly liquid assets declined. The share of unencumbered liquid assets has declined over time from 105% of NAV in 2022 to 97% in 2023 and to 88% of NAV end-2024. However, when expressed in percentage of AuM, the share of liquid assets increased from 20% in 2022 to 26% in 2023, before declining to 22% in 2024.

Given the stability of the interest rate sensitivity, another approach to gauge the ability of LDI funds to face liquidity demands is to look at the ratio of unpledged bonds to total assets: $\frac{A_u}{A_u+A_p}$.

When there is no price impact ($\alpha = 0$), this ratio determines δ^{max}, the maximum interest rate shock a fund can withstand. Chart 15 shows the relationship between unencumbered highly liquid assets and estimated liquidity buffers/shortfalls for a sample of 131 funds using repo across the three periods. There is a clear positive relationship between the stocks of assets and potential excess liquidity. Funds with low holdings of unencumbered assets are those which would face a liquidity shortfall in the stress tests. The relationship holds across the three periods, although it is weaker for 2023 and 2024 compared to 2022.

Chart 15
Highly liquid assets and liquidity shortfalls
High unencumbered assets mitigate liquidity demands



Note: Share of unencumbered assets and liquidity shortfall/buffer in % of total assets.
Sources: AIFMD, EMIR, SFTR, ESMA.

Conclusion

The use of leverage by investment funds can raise risks to financial stability through the liquidation channels: when faced with adverse shocks, funds might need to liquidate assets to meet liquidity demands.

We show how the combination of leverage stemming from repo borrowing and derivatives, and high portfolio overlap and concentration among GBP LDI funds can result in stress for this cohort of funds and for the sovereign bond market they invest in.

Our liquidity stress test results indicate that the resilience of LDI funds has improved since the mini-budget crisis of 2022, with the liquidity shortfall declining from EUR 9bn to 3bn in 2024, when considering highly liquid assets. However, results for end-2024 show that a subset of funds might still face challenges in meeting liquidity demands in case of a large interest rate shock. Looking forward, our stress test and risk analysis framework can be used to assess similar risks in other non-bank financial institutions.

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