Pension Liquidity Risk*

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Abstract

Pension funds use interest rate swaps to hedge the interest rate risk arising from their liabilities. Analyzing regulatory data on Dutch pension funds, we first show that pension funds with higher hedging demand use swaps more aggressively. These swap positions expose pension funds to the risk of facing margin calls, which can exceed 10% of their total assets, when interest rates rise. Pension funds respond to realized margin calls by selling safe government bonds with medium-term maturities. This procyclical selling behavior adversely affects the prices of the sold bonds and thereby exposes pension funds to market liquidity risk.

Keywords: Pension funds, fixed income, interest rate swaps, liability hedging, liquidity risk, margin calls, price impact.
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Introduction

Pension funds are huge institutional investors with total pension assets that often exceed the gross domestic product (GDP) of their home countries (OECD, 2022). Given the sheer size of the pension sector, pension funds' hedging decisions have received substantial attention in the academic literature, highlighting their demand for long-dated government bonds and interest rate swaps (e.g., Greenwood and Vayanos, 2010, Greenwood and Vissing-Jorgensen, 2018, Klingler and Sundaresan, 2019, Jansen, 2024). By contrast, little is known about the adverse effects of pension funds' hedging strategies using derivatives. For instance, if a pension fund receives the fixed rate in a long-dated interest rate swap, an increase in interest rates requires the fund to post additional margin, typically in the form of cash. This additional margin requirement, or margin call, can force the pension fund to sell part of its asset holdings at transaction prices below their fundamental value and therefore expose it to market liquidity risk (Brunnermeier and Pedersen, 2009).

To fill this void, we utilize unique regulatory data on Dutch pension funds that allow us to study the link between pension funds' derivative positions, asset holdings, and asset prices. Focusing first on pension funds' hedging decisions, we find that pension funds with lower funding ratios (i.e., ratios between the present values of their assets and liabilities) use interest rate swaps more aggressively. These swap positions reduce pension funds' interest rate risk, but introduce the risk of substantial margin calls—which can exceed 10% of the pension funds' total assets—when interest rates rise. Turning to the implications for pension funds' asset allocations, we find that pension funds with large swap positions reduce their bond holdings in response to rising interest rates. When margin calls materialize during periods of significant increases in interest rates, pension funds primarily sell their most liquid securities; safe government bonds with a medium-term maturity between one and seven years. This selling behavior has an adverse price impact. Hence, due to margin calls from their derivative positions, pension funds' hedging decisions can even impact bond yields at the shorter end of the maturity spectrum.

In our study, we use unique regulatory data on the Dutch pension system over the 2012 to 2022 period. With a total of $2.04 trillion in assets under management (AUM) as of 2021, the Dutch pension system represents 53% of all pension assets in the Euro area (ECB, 2022) and corresponds to 209.5% of the Dutch GDP (OECD, 2022). In addition, the Dutch pension system is an ideal laboratory for investigating the link between derivatives usage and asset holdings, given our access to detailed information on pension fund liabilities, asset allocations, and derivative positions.

As a starting point for our analysis, we document three stylized facts about pension funds and their swap usage. First, the pension funds in our sample mainly receive the fixed rate in long-dated swaps, and the aggregate size of their positions is comparable to that of the Dutch banking system. Second, to hedge the interest rate risk of their liabilities, pension funds mainly use swaps rather than bonds, with approximately 67% of their portfolio duration coming from swap positions. Third, realized margin calls are substantial, averaging 4.5% of the pension funds' AUM when interest rates rise and usually exceeding the cash holdings by several orders of magnitude. In extreme cases, margin calls even exceed 10% of the pension funds' AUM. For 84% of the funds in our sample, the magnitude of realized margin calls also exceeds the improvement in funding ratios that coincides with rising interest rates due to the negative duration gap between assets and liabilities.

We next derive and test three hypotheses. Our first hypothesis is that pension funds with lower funding ratios use more interest rate swaps. The rationale for this hypothesis is that pension funds cannot take levered bond positions. Instead, they can use interest rate swaps to hedge interest rate movements while maintaining their strategic asset allocations. We find that pension funds with lower funding ratios have larger swap positions and simultaneously lower cash holdings. Hence, these larger swap positions expose pension funds to the risk of forced portfolio liquidations when interest rates—and therefore the margin requirements on their swap positions—rise. This *liquidity risk* is more pronounced for pension funds with a worse funding ratio.

Our second hypothesis is that pension funds respond to increasing swap rates by selling their most liquid assets. As a first test of this hypothesis, we examine how increasing swap rates affect pension funds' asset allocations. We find that pension reduce their bond holdings when interest rates increase. These reductions go against the rebalancing effect driven by strategic asset allocations, which would require the pension fund to *purchase* fixed income securities in response to falling bond prices. Phrased differently, the selling patterns we observe are *procyclical* while rebalancing due to strategic asset allocation goals is countercyclical. To connect the selling of fixed income securities to margin calls, we show that the reduction in bond holdings is driven by pension funds with longer swap durations.[1] This *cross-sectional* link between increasing swap rates and pension funds' reductions in fixed income holdings mitigates the concern that our findings are driven by the endogenous determination of interest rates. To further alleviate such concerns, we show that our results are robust to instrumenting the 20-year swap rate with the effect of monetary policy surprises on the 20-year Euro OIS rate. In addition, pension funds with high bond durations instead of high swap durations do not sell bonds when interest rates rise. Hence, it is unlikely that the observed pattern is driven by pension funds' expectations about future bond returns.

To examine how pension funds respond to large increases in swap rates and the associated

[1] We obtain qualitatively and quantitatively similar results using reported *realized* margin calls, rather than swap durations, that became available as of 2018.

margin calls, we next study pension funds' asset holdings at the security level. We first document that pension funds sell cash-like assets, such as money market funds (MMFs), in response to substantial increases in interest rates.[2] However, for most pension funds, these sales are insufficient to cover their margin calls during these periods. Pension funds' second-most liquid assets are German and Dutch government bonds (the only Euro-denominated government bonds with a triple-A rating from all major rating agencies over our sample period) and consistent with our hypothesis, pension funds sold these government bonds in response to margin calls. Specifically, the selling of safe government bonds concentrates in bonds with maturities between one and seven years, which we show are more liquid than longer-dated bonds.

Because pension funds are major investors in government bond markets, our third hypothesis is that their bond sales have an adverse price impact. To test this hypothesis, we construct a bond-level proxy for liquidity risk from margin calls. This measure is the average of the pension funds' swap duration, weighted by the size of the funds' positions in that bond. We then examine the link between price changes and the lagged liquidity risk measure. Consistent with our hypothesis, we find that bonds more exposed to liquidity risk have significantly lower returns during months with substantial increases in interest rates. In terms of economic magnitude, we find that a one standard deviation increase in the margin call risk measure reduces bond returns at the medium-term of the maturity spectrum by 5.5 basis points, or 8.5% of the average medium-term bond returns during periods of interest rate surges. Hence, margin calls from derivatives expose pension funds to market liquidity risk. In addition, after selling the medium-term bonds, pension funds eventually need to re-

[2] This finding aligns with Ghio, Rousova, Salakhova, and Bauer (2023), who demonstrate that MMF outflows in March 2020 were driven by investors facing margin calls. Stress-tests also reveal that pension funds consider the sales of MMF shares as a key source to obtain liquidity (DNB and AFM, 2024).

balance their portfolio to comply with their strategic asset allocation. As such, our estimates are a lower bound of the total transaction costs faced by pension funds.

We conclude our price impact analysis by applying the granular instrumental variables (GIV) approach developed by Gabaix and Koijen (2022, 2024). In doing so, we estimate the overall impact of pension funds' margin calls on government bond yields. Our estimates suggest that when the 3-year safe Euro yield rose by 87 basis points in August 2022, sales by pension funds due to margin calls contributed 8.7 basis points to this yield rise, or 10% of the total increase.

Our study reveals that hedging with interest rate swaps exposes pension funds to liquidity risk due to margin calls, challenging the traditional view that pension funds stabilize financial markets due to their long-term investment horizons (e.g., Timmer, 2018; Grinblatt and Keloharju, 2000; Chodorow-Reich, Ghent, and Haddad, 2021). The liquidity risk highlighted in our study arises as an unintended consequence of a combination of two financial regulations designed to enhance the stability of the financial system. First, regulators incentivize pension funds to hedge their interest rate exposure, and pension funds respond to these requirements by using interest rate swaps. Second, stricter margin requirements and mandatory central clearing of these over-the-counter (OTC) derivatives expose swap users to liquidity risk through margin calls. Importantly, we show that this liquidity risk is more severe for more fragile pension funds, that is, those with a low funding status.

This adverse effect of the two regulations expands beyond the Dutch pension sector. Pension funds in other jurisdictions, such as the US and Japan, use interest rate swaps for hedging (e.g., Klingler and Sundaresan, 2019). Most prominently, the sudden spike in British interest rates in September and October 2022 triggered margin calls and subsequent fire sales from UK pension funds, underscoring the vulnerabilities inherent in pension funds' interest rate hedging strategies (e.g., U.K. Parliament, 2022; IMF, 2023). Moreover, the same issues arise for European insurance companies (who face a similar regulatory framework under Solvency II) and the US insurance sector, which also adheres to capital requirements and mandatory collateral requirements. Highlighting this similarity, we find a correlation between realized margin calls and subsequent reductions in safe fixed income allocations for the European insurance sector based on publicly available data from EIOPA (see Internet Appendix IA.6).

Our paper contributes to three streams of literature. First, we contribute to the extensive literature that examines the risk management and hedging behavior of pension funds and insurance companies. The link between regulatory constraints, hedging, and asset allocation decisions of pension funds and insurance companies has been studied by, among others, Adams and Smith (2009), Ellul, Jotikasthira, and Lundblad (2011), Andonov, Bauer, and Cremers (2017), Sen (2023), Ellul, Jotikasthira, Kartasheva, Lundblad, and Wagner (2022), Koijen and Yogo (2021), Ge and Weisbach (2021), and Koijen and Yogo (2022). For instance, Sen (2023) shows that regulatory incentives for hedging the risks of variable annuities lead insurance companies to use derivatives contracts. Similarly, we show that regulatory constraints prompt pension funds to use more interest rate swaps. Our unique contribution to this literature is to highlight the feedback effect from hedging decisions to the asset allocation decisions by pension funds. Specifically, we show how hedging with interest rate swaps exposes pension funds to liquidity risk from margin calls that can ultimately lead to selling pressure on (safe) assets. Moreover, our results expand the literature on pension funds' price impact on long-dated securities (e.g., Greenwood and Vayanos, 2010, Domanski, Shin, and Sushko, 2017, Greenwood and Vissing-Jorgensen, 2018, Klingler and Sundaresan, 2019, Jansen, 2024, Khetan, Li, Neamtu, and Sen, 2023) by showing that pension funds' selling behavior can even affect the rest of the yield curve spectrum.

Second, our results on safe asset sales are related to the literature on (reverse) flights to liquidity. Ben-David, Franzoni, and Moussawi (2012) and Manconi, Massa, and Yasuda (2012) show that US hedge funds and mutual funds responded to investor redemptions during the global financial crisis by selling their most liquid assets first. Ma, Xiao, and Zeng (2022); Jiang, Li, Sun, and Wang (2022) show similar selling behavior for US mutual funds during the market turmoil in March 2020. Czech, Huang, Lou, and Wang (2021) also focus on March 2020 and show that UK institutions sold their domestic safe assets to meet margin calls on their short-dollar FX positions. Alfaro, Bahaj, Czech, Hazell, and Neamțu (2024) examine bond sales of UK non-bank institutions stemming from solvency hedging in September and October 2022. Our study adds to this literature by demonstrating that the pecking order of selling the most liquid assets first is not confined to a specific episode or extreme crisis. In response to significant increases in interest rates, pension funds systematically and procyclically sell safe and liquid bonds to meet margin calls from their swap positions.

Finally, we contribute to the broader literature on uninformed demand shocks and price impact (e.g., Shleifer, 1986; Wurgler and Zhuravskaya, 2002; Greenwood, 2005; Chang, Hong, and Liskovich, 2015; Koijen and Yogo, 2019). In particular, Da, Larrain, Sialm, and Tessada (2018) and Aldunate, Da, Larrain, and Sialm (2023) show that frequent and uninformed re-allocations between equity and bond funds by Chilean pension investors generate significant price pressure in the Chilean stock and foreign exchange markets. We contribute to this literature by showing that margin calls from derivative positions are another source of uninformed demand shocks that create spillover effects in financial markets. In addition, Pinter (2023) and Pinter, Siriwardane, and Walker (2024) offer a micro-structure analysis of the liquidity dry-ups during the UK pension crisis of late 2022. While the UK pension crisis was a major shock, our study extends beyond one single episode and demonstrates how pension funds' regulatory constraints prompt swap usage, which introduces margin call risk and leads to forced sales of safe assets during periods of interest rate surges.

1 Background and Stylized Facts

In this section, we first provide the relevant institutional background of the Dutch pension system, followed by a description of the data and three stylized facts that motivate our analysis.

1.1 The Dutch Pension System

There are three types of Dutch pension funds: (i) corporate pension funds, (ii) industry-wide pension funds, and (iii) professional-group pension funds.[3] Unlike in other countries, such as the US, all three types of Dutch pension funds are subject to the same regulatory framework. This homogeneity is essential for our empirical analysis, where we pool all three types of pension funds.

1.1.1 Pension Regulation

To assess the financial health of a pension fund, regulators focus on two key indicators. First, the *funding ratio* captures the ratio between pension assets and pension liabilities. The numerator of the funding ratio is the market value of the pension assets and the denominator

[3]While corporate pension funds are set up by individual firms, industry-wide pension funds cover specific industries or sectors (e.g., civil servants), and professional-group pension funds cover workers within a particular profession (e.g., veterinarians or pharmacists).

is the present value of the pension liabilities. To compute the present value of the liabilities, regulators use a combination of Euro-denominated interest rate swap rates and a fixed rate known as the Ultimate Forward Rate (UFR).[4] Second, the *required funding ratio* is based on a pension fund's risk profile. The required funding ratio is derived from a 97.5% probability that the funding ratio does not drop below 100% within the next year and is comparable to the value-at-risk (VaR) constraint in bank regulation. The higher the required funding ratio, the more risk the pension fund is willing to take, and consequently, the larger the buffer it needs to maintain.[5]

The minimum funding ratio is 104.2% and plans with funding ratios below this threshold are not allowed to index their pension payments to inflation. The allowed level of indexation then increases monotonically and only plans with funding ratios above 140% are allowed to offer full indexation. In addition, if a pension fund does not meet its minimum or required funding requirements, it must submit a recovery plan to the regulator. The reason for these high funding requirements is that a Dutch pension sponsor has no obligation to provide financial aid to its pension plan if it becomes underfunded. By contrast, pension funds in other jurisdictions (e.g., the US or Japan) can be substantially underfunded, but in these instances, the pension sponsor is ultimately liable for the pension liabilities.

1.1.2 Pension Risk Management

Pension risk management involves two components. First, the board of the pension fund agrees on the strategic asset allocation, considering the risk-return profile of the pension

[4] More precisely, the first step in computing the discount rate involves extracting zero-coupon rates from swap rates and converting them into forward rates. For maturities above 20 years, the second step is to calculate a weighted average between the market-implied forward rates and the UFR. For additional details on the discounting rules, see Section 2 of Jansen (2024).

[5] We provide details and sample calculations for the required funding ratio in Internet Appendix IA.2.

assets. For instance, the board might require the pension fund to allocate 50% of its assets to fixed income securities and the remaining 50% to equities. Second, because pension funds face interest rate risk due to the long duration of their liabilities, the board also determines the level of interest rate risk the pension fund can take. These risk-taking decisions are typically revisited every three years and changes in risk-taking are subject to regulatory constraints when a pension fund faces a funding gap, that is, when the funding ratio is below the required funding ratio.

The long duration of the liabilities exposes pension funds to substantial interest rate risk. Because the present value of the pension liabilities is calculated using swap rates, a drop in the swap rate increases pension liabilities. Unless the value of the pension assets increases by the same amount, a drop in interest rates deteriorates the funding status of the plan. Throughout this paper, we use the term "duration" to capture the sensitivity of assets and liabilities to changes in interest rates.

The pension fund can hedge this sensitivity to interest rates in three ways. First, it can invest the majority of its assets in long-dated bonds and thereby match the duration of its assets and liabilities.[6] The drawback of this approach is that bonds have substantially lower expected returns than equities, which lowers the probability that the fund can provide full indexation in the future. Second, it could use repurchase agreements to take a levered position in fixed income securities while still allocating a large part of its portfolio to stocks. However, while British pension funds are allowed to use direct leverage (e.g., Andersson, 2023), the law in the Netherlands limits the use of repurchase agreements for Dutch pension funds to fill temporary liquidity needs.[7] Third, the pension fund can take a fixed receiver

[6]As we lay out in Appendix IA.2, pension regulation imposes that equities are not exposed to interest rate risk, so pension funds need to use fixed income securities to hedge the duration risk of their liabilities.

[7]The law refrains pension funds from straight borrowing. They could however lend out bonds to meet temporary liquidity needs. Hence, pension funds with a sudden cash need could temporarily fulfill these

position in interest rate swaps to match the duration of its liabilities. While pension funds could combine these approaches to hedge their interest rate risk, we show later that interest rate swaps are their preferred hedging tool.

Hedging interest rate risk with swaps has two advantages for pension funds. First, because engaging in an interest rate swap requires only a small initial investment (initial margin requirement), it allows the pension fund to allocate a large portion of its investments to more remunerative asset classes than fixed income. Second, hedging with swaps has the same impact on the required funding ratio as purchasing (safe) Euro-denominated bonds. In practice, as we demonstrate in the following section, pension funds do not fully hedge the interest rate risk of their liabilities. Hence, most pension funds have a duration gap with their liabilities having a longer duration than their assets.

In addition to hedging the duration risk of their liabilities, pension funds also invest in bonds with a range of different maturities. These investments are critical for pension funds to match the cash flows from their liabilities (Leibowitz, 1986; Fabozzi, Tong, and Zhu, 1990; Jansen, 2024). In line with the notion that pension funds have long-dated liabilities, pension funds face large cash flows from liabilities with more than 15 years to maturity (see Figure A1 in the Appendix). However, pension funds also have a significant amount of liabilities with cash flows that are due within the next seven years. Hence, pension funds also invest in medium-term bonds with maturities of less than seven years to match the shorter-term cash flows from their liabilities.

needs by using repo transactions but would eventually need to liquidate part of their asset portfolios if the cash need persists.

1.2 Interest Rate Swaps and Margin Requirements

Engaging in a swap position typically requires pension funds to post an initial margin when initiating the swap and a variation margin if the value of the derivative declines (BCBS and IOSCO, 2015). The initial margin is a fixed amount that covers the potential losses if a counterparty defaults shortly after the contract is closed. The variation margin reflects the mark-to-market value of the swap and often exceeds the initial margin by several orders of magnitude (e.g., Czech et al., 2021). If interest rates increase, the mark-to-market value of a fixed-receiver swap decreases, and pension funds that use swaps for duration hedging must post additional variation margin. We refer to such increases in variation margin as *margin calls* and note that they are especially severe if the variation margin is posted in cash.[8] In particular, sharp increases in interest rates expose pension funds that use swaps for duration hedging to market liquidity risk if the margin requirements exceed the funds' cash holdings. We illustrate this point in a numerical example in the Internet Appendix (Table IA.8).

Since 2012, the European Market Infrastructure Regulation (EMIR) requires European pension funds to exchange collateral on their derivative positions (European Parliament and Council, 2012). Until June 2023, pension funds could choose the type of collateral posted in their bilateral derivative positions and were exempt from central clearing (ESMA, 2022). Central clearing requires all derivatives counterparties to post cash collateral, and even though central clearing was not mandatory for pension funds during our sample period, most non-centrally cleared trades use cash as collateral (ISDA, 2017). Cash is the predominant form of collateral in derivatives contracts because it allows dealers to hedge their positions using central clearing. This cash preference makes bilaterally-cleared swaps susceptible to discriminatory pricing (Cenedese, Ranaldo, and Vasios, 2020) and gives pension funds an

[8] If pension funds *receive* cash margins they invest this cash according to their strategic asset allocation.

incentive to use centrally-cleared contracts. In addition, Czech et al. (2021) explain that the introduction of the leverage ratio makes cash the preferred collateral type for banks.

1.3 Data

We obtain detailed information on the liabilities, assets, and derivatives usage of all Dutch pension funds from the Dutch Central Bank ("De Nederlandsche Bank", henceforth DNB). Granular data on all three types of balance sheet items are rare and make the Dutch pension system an ideal laboratory to study the feedback from pension funds' derivatives usage to their asset allocation.

Pension funds report quarterly to DNB and started providing details on their derivative positions in the first quarter of 2012. We drop pension funds that report for less than four consecutive quarters from our analysis and focus on the sample period between 2012Q1 and 2022Q4. Our final sample comprises 255 distinct pension funds.

Table 1 contains summary statistics of our sample. The average pension fund has €6.70 billion in AUM and allocates 55% of its portfolio to bonds and 33% to equities. The average funding ratio is 111% with a large variation from a 5th percentile of 92% to a 95th percentile of 134%. The average required funding ratio is 117%, ranging from a 5th percentile of 109% to a 95th percentile of 125%. The net contributions, defined as the pension contributions minus pension payments, equal on average 0.21% of AUM per quarter.[9] Pension funds have an average liability duration of 19 years and a substantially lower average portfolio duration of approximately 12 years.[10] Interestingly, when examining the asset and swap duration separately, we observe that around 67% ($= 7.5/11.04 \times 100$) of the median portfolio duration

[9]The pension contributions and payments are only reported on an annual basis. We assume they stay constant throughout the year and divide both by four to obtain the quarterly net contributions.

[10]We infer the bond and swap durations from the regulatory filings. We provide more details in Internet Appendix IA.3.

comes from swaps.

In addition to these quarterly data, DNB collects monthly information on the asset holdings of the largest pension funds. This sample comprises only 42 pension funds, but covers between 85% and 90% of the total AUM of Dutch pension funds. We show in Internet Appendix Table IA.3 that apart from size, the pension funds in the holdings data sample have similar characteristics compared to the full sample of pension funds. Asset holdings do not "look through" underlying mutual fund investments, except for the largest two pension funds. For these pension funds, following Jansen (2024), we know pension funds' shares in mutual funds and we can use the reported holdings of mutual funds to obtain the underlying indirect holdings.[11] Panel B of Table 1 shows summary statistics of the monthly holdings, highlighting that pension funds in our sample invest the majority (66%) of their fixed income portfolio in government debt. A large portion, on average 53% of pension funds' government bond portfolios, is allocated to German and Dutch government debt.

[Insert Table 1 near here]

1.4 Stylized Facts

We now present three stylized facts that motivate our analysis. First, we show that pension funds have huge fixed receiver positions in Euro-denominated swaps. Second, comparing the duration of asset portfolios and swap positions, we highlight large fluctuations in the duration of pension funds' swap positions while asset durations remain largely constant. Finally, we show that pension funds' cash buffers are not sufficient to cover margin calls and

[11] After this adjustment, as shown in Jansen (2024), the fraction of direct assets to total assets equals 85% on average.

the size of the margin calls exceeds the improvement in funding ratios as a result of rising interest rates most of the time.

1.4.1 Swap Usage By Dutch Pension Funds

Figure 1 shows the fraction of pension funds in our sample that use interest rate swaps. For our full sample, this fraction increased from 75% in 2012 to 95% in 2022. For the 42 large pension funds, the fraction is even higher and equal to 100% for most of our sample period. We focus our analysis on interest rate swaps because they are the main hedging tool of Dutch pension funds with volumes that are several orders of magnitude larger than for other derivative contracts (see Figure A2 in the Appendix). Illustrating the role of Dutch pension funds in the swap market, the second panel in Figure 1 shows the net notional of outstanding Euro-denominated interest rate swaps in 2020, split by different counterparties. We only observe these volumes for Dutch counterparties and the figure shows Dutch pension funds are net receivers of interest rate swaps with maturities above ten years. Their receiver volumes are of similar magnitude to the net notional of Dutch banks, dwarfing the swap usage of Dutch insurance companies and other Dutch counterparties. To put the numbers from Figure 1 into perspective, we estimate that Dutch pension funds held around 27.6% (3.2%) of the European non-centrally cleared (total) swap positions.[12]

[Insert Figure 1 near here]

[12] This number is based on back-of-the envelope calculations using data from the BIS (https://www.bis.org/statistics/derstats.htm). In H2 2020, the total gross notional amount of all outstanding swaps was $466.4 trillion. Out of this amount, 75% were interest rate swaps, 22% had a maturity above five years, 28% were Euro-denominated, and 12% were not held by central counterparties. Multiplying these fractions suggests the total size of the European swap market with maturities longer than five years was around $21.5 trillion with $2.5 trillion held by institutions other than central counterparties. Using our data, we find the gross notional of interest rate swaps with more than five years to maturity held by Dutch pension funds was $694 billion in 2020.

1.4.2 Interest Rate Hedging and Swap Usage

Figure 2 shows the average liability duration and portfolio duration of the pension funds in our sample over time. As we can see from the figure, the average liability duration is around 19 years while the average portfolio duration—combining the duration of assets and derivatives—fluctuates around 12 years. Hence, the average pension fund in our sample has a duration gap of approximately 7 years. In addition, the bottom line in Figure 2 shows the average asset duration, constructed as the duration of the portfolio, excluding derivatives. In contrast to the total portfolio duration, the asset duration is virtually constant around 4 years.[13] Hence, Figure 2 suggests that pension funds adjust their portfolio duration using interest rate swaps and leaving their bond durations largely unchanged.

[Insert Figure 2 near here]

To highlight that the swap positions are used for hedging, we show in the Internet Appendix (Figure IA.2) that pension funds' funding ratios would be more volatile if they had not used interest rate swaps. This result is similar to the findings of Sen (2023) for US insurance companies.

1.4.3 Pension Funds Face Substantial Margin Call Risk

We now illustrate how using interest rate swaps exposes pension funds to liquidity risk when interest rates increase. To that end, we construct a proxy of realized margin calls. We first calculate the duration of each pension funds' swap portfolio relative to its AUM and multiply this number with the percentage point change in the 20-year swap rate during

[13] To put this asset duration into perspective, it is important to recall that the average pension fund in our sample invests approximately 50% of its assets in bonds. Because under the regulatory treatment equities have no exposure to interest rates, the total asset duration is about half that of the bond portfolio duration, which on average equals 8 years.

periods of substantial increases in interest rates. To identify such periods, we use changes in the 20-year swap rate and focus on incidents where the 10-day change is above 40 basis points. Because we only observe monthly asset allocations of pension funds, we focus on the months in which we observe the largest rate surges. This approach gives eight months with substantial increases in interest rates: May 2015, June 2015, March 2020, April 2022, June 2022, August 2022, September 2022, and December 2022. We provide additional details on the evolution of swap rates and the selected periods of interest rate surges in the Appendix (Table A1) and Internet Appendix (Figure IA.1).

Panel (a) of Figure 3 shows the distribution of realized margin calls during periods of interest rate surges. The average realized margin call equals 4.5% of AUM and exceeds 10% for a substantial part of our sample. To put these numbers into perspective, Panel (b) shows the distribution of realized margin calls adjusted for cash holdings as fraction of total assets.[14] For 74% of the pension funds in our sample, the realized margin calls are larger than their available cash buffers. As of 2018, pension funds directly report the margin calls they would receive when interest rates rise to the regulator. We illustrate the close link between our estimates and the reported numbers in the Internet Appendix (Figure IA.3).[15] We also show throughout the paper that all our results are qualitatively and quantitatively similar when using the reported margin calls instead of our proxy (despite losing the first years of our sample period).

[Insert Figure 3 near here]

To shed more light on the magnitude and implications of margin call risk, recall from

[14]Cash holdings include money market funds, as well as short-term bonds and (term) deposits with initial maturities of less than one year.

[15]The reported margin calls tend to be lower than our proxy because some funds have buffers against margin calls in the form of cash holdings in a margin account.

Section 1.3 that most pension funds have a negative duration gap between their assets and liabilities. Hence, increasing interest rates typically improve the overall funding status of pension funds because they lower the present value of pension liabilities more than the present value of pension assets. To put margin calls from derivatives into perspective with the potential improvements in the overall funding status, we compute changes in funding ratios as follows:

$$\Delta FR_{i,t} = \frac{A_{i,t} - L_{i,t} - \big(A_{i,t-1} - L_{i,t-1}\big)}{A_{i,t-1}}, \tag{1}$$

with $A_{i,t}$ the AUM of pension fund i at time t and $L_{i,t}$ the corresponding value of the liabilities.

Figure 4 shows a scatterplot of $\Delta FR_{i,t}$ against margin call risk, also taken relative to AUM. As indicated by the figure, the margin call risk typically outweighs the improvement in funding status. More precisely, in 84% of the cases, the margin call risk exceeds the funding ratio improvement. Moreover, Figure 4 show that, in many cases, the funding ratio deteriorates despite the large increases in interest rates. This deterioration is driven by large negative stock returns during times of substantial interest rate increases, which lowers the funding ratio due to drops in the value of pension assets. To illustrate this point, note that during episodes of substantial rate hikes, the average stock return (measured with the MSCI Index) is −6.4% while the average bond return (measured with the European Investment Grade Bond Index) is −3.2%. We provide additional details on the stock and bond returns during these episodes in the Appendix (Table A1).

[Insert Figure 4 near here]

2 Hypotheses

Building on the institutional background and stylized facts from Section 1, we now derive three hypotheses to guide our empirical analysis.

Klingler and Sundaresan (2019) link drops in long-dated swap rates to decreases in the funding status of defined benefit (DB) pension plans, arguing that pension funds with a worse funding status use more swaps. We modify their arguments to highlight that pension funds use swaps for hedging. Assume the funding ratio of a pension fund deteriorates. If the pension fund wants to keep its strategic asset allocation unchanged (i.e., invest the same fraction of its assets in stocks), it needs more interest rate swaps for duration hedging. The reason for the higher swap demand is that the pension fund is not allowed to use direct leverage to increase its bond holdings. Hence, a lower funding status implies that a pension fund that keeps its strategic asset allocation unchanged has less bonds that hedge its duration risk and therefore needs more swap contracts for the same hedge. We illustrate this point with a numerical example (Table A4 in the Appendix) and through an illustrative model in the Internet Appendix (Section IA.4). Our first hypothesis is that pension funds hedge more using interest rate swaps when the funding position deteriorates.

Hypothesis 1. *Pension funds with a worse funding status use more swaps.*

This hedging reduces the adverse impact of falling interest rates but exposes the pension fund to the risk of margin calls when interest rates, and especially swap rates, increase. As discussed in Section 1, most margin calls require cash collateral and the amount of cash held by pension funds is substantially lower than the realized margin calls in our sample (Figure 3). Hence, sharp increases in swap rates can force pension funds to liquidate parts of their portfolios. Investors typically respond to liquidity shocks by selling their most liquid assets first (e.g., Scholes, 2000; Ben-David et al., 2012; Manconi et al., 2012; Ma et al., 2022) and we hypothesize pension funds follow a similar pattern. Given that bond sales typically incur lower transaction costs compared to stocks (e.g., Chordia, Sarkar, and Subrahmanyam, 2005), we expect pension funds to react to increasing swap rates by liquidating parts of their bond holdings. We further expect that these liquidations are stronger for pension funds with larger swap positions. Examining this hypothesis further, pension funds should liquidate their safest bond holdings first because safe (government) bonds typically benefit from lower transaction costs (e.g., Chordia et al., 2005) and smaller liquidity premiums (Meyer, Reinhart, and Trebesch, 2022).

Hypothesis 2. *(a) Increases in swap rates coincide with a reduction in bond holdings. This link is more pronounced for pension funds with longer swap durations.*

(b) During periods of substantial increases in swap rates, pension funds sell their safest and most liquid bonds first.

To test part (b) of Hypothesis 2, we assume that medium-term government bonds from safe issuers are the most liquid part of the pension funds' portfolio (e.g., O'Sullivan and Papavassiliou, 2020). We motivate this assumption in Figure IA.8 in the Internet Appendix, which highlights significantly lower bid-ask spreads for government bonds with less than seven years to maturity. It is also worth noting that, unlike short-term bonds, medium-term bonds are not considered as cash-like assets. As discussed in Section 1, pension funds typically hold these securities to match the cash flows from their medium-term liabilities (Figure A1).

Our unique setting mitigates two common concerns. First, changes in bond holdings could be correlated with changes in interest rates because of portfolio rebalancing. However, rising interest rates correspond to lower bond prices and pension funds not facing margin calls would therefore *increase* their bond holdings to adhere with their strategic asset allocation. Hence, *lower* bond allocations in response to swap rate increases are not driven by the funds' rebalancing efforts. In addition, while rebalancing due to strategic asset allocation goals can take place in the months after the interest rate increase, the pension fund must post additional margin in the same month of the increase. Second, changes in swap rates could be endogenous to pension funds' portfolio rebalancing. Incorporating pension funds' swap positions into our analysis mitigates this concern. If, for instance, lower fixed income allocations by pension funds were pushing swap rates up, we would not expect a stronger effect for pension funds with larger swap holdings.

Pension funds are huge investors in the sovereign bond market and, as noted by Chang et al. (2015) and Da et al. (2018), among many others, selling pressure by large investors affects the prices of the traded securities. Hence, building on Hypothesis 2, our final hypothesis is that the selling by pension funds during times of substantial swap rate increases has an adverse price impact.

Hypothesis 3. *During periods of substantial increases in swap rates, the selling pressure from pension funds has an adverse price impact on safe medium-term government bonds.*

3 Swap Usage and Hedging Demand

In this section, we test Hypothesis 1 by connecting pension funds' swap usage to hedging demand. Figure 5 shows a binned scatter plot of lagged funding ratios against portfolio durations. Pension funds with low lagged funding ratios have a longer portfolio duration compared to pension funds with high lagged funding ratios.[16] This is suggestive evidence in

[16]In addition, Figure IA.4 in the Internet Appendix illustrates the strong negative relation between the cross-sectional average funding ratio and swap durations over time.

favor of Hypothesis 1.

[Insert Figure 5 near here]

We next study the relationship between portfolio duration ($Dur_{i,t}$) and the lagged funding ratio ($FR_{i,t-1}$) in panel regressions of the following form:[17]

$$Dur_{i,t} = \beta_0 FR_{i,t-1} + \gamma C_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{i,t}, \tag{2}$$

where $C_{i,t-1}$ indicates time-varying fund level controls that include the lagged duration of the pension liabilities, the lagged logarithm of the funds' AUM, lagged net contributions (% AUM), and the lagged required funding ratio.

Column (1) of Table 2 confirms the motivating evidence from Figure 2; funds with low funding ratios have a higher portfolio duration than funds with high funding ratios. Column (2) shows that these results are robust to including fund and time fixed effects, and the link between the lagged funding ratio and portfolio duration gets larger in economic magnitude. To interpret the economic magnitude of this effect, recall from Table 1 that the standard deviation of the funding ratio is 15.91%. Hence, Column (2) shows that a one standard deviation increase in the funding ratio is associated with a portfolio duration that is lower by 0.96 ($= -6.032 \times 0.1591$) years.

[Insert Table 2 near here]

A critical question for our analysis is whether longer portfolio durations of constrained pension funds are driven by swap usage or longer-dated bond portfolios. To examine this

[17] We cluster the standard errors in this part of the analysis at the fund level to allow for correlation in the error terms within a pension fund. The coefficient on the lagged funding ratio remains statistically significant if we double cluster at the fund and time level, but since we have a relatively small time-series dimension, our baseline does not cluster at the time level (Angrist and Pischke, 2009).

question, we replace the portfolio duration with the swap duration on the left-hand side of Equation (2). This test corroborates the suggestive evidence from Figure 2 that most of this effect comes from swap durations. Column (3) of Table 2 shows that the link between lagged funding ratio and swap duration is statistically significant and of comparable magnitude to the coefficients from Column (1). In addition, adding time fixed effects as controls, Column (4) shows that a one standard deviation decrease in the funding ratio increases the swap duration by 0.96 ($= -6.033 \times 0.1591$) years. By contrast, Columns (5) and (6) suggest no link between lagged funding ratio and the duration of the asset portfolio.

In addition, our analysis is robust to two variations that we discuss in the Internet Appendix of the paper. First, in Table IA.1, we run the same regression in first differences to study how changes in funding ratios affect changes in swap durations. We address the endogeneity issue that arises when using contemporaneous changes in the funding ratio by applying an IV methodology. Our findings show that a decrease in the funding ratio corresponds to an increase in swap durations. Second, Table IA.2 shows that our results are robust to a regression specification that includes the lagged funding gap instead of the funding ratio. The funding gap serves as a direct and even more accurate proxy for the regulatory constraints faced by pension funds (see Section 1.1). The results in Table IA.2 are qualitatively and quantitatively similar to our baseline results, which is expected given the high correlation of -0.95 between the funding ratio and the funding gap.

To conclude our analysis, we show pension funds with worse funding ratios do not have higher cash holdings. This is in line with the theory of Ang, Chen, and Sundaresan (2012), who show that underfunded pension funds invest their available capital in equities to maximize the probability of becoming fully funded in the future. Hence, the observed larger swap positions for pension funds with a worse funding status expose them to more liquidity risk from margin calls. To make this point, Figure 6 shows a binned scatter plot of cash allocations against the lagged funding ratio. As we can see from the figure, if anything, pension funds with tighter constraints have *lower* cash holdings.[18]

[Insert Figure 6 near here]

4 Response to Margin Calls from Swaps

We now move on to testing Hypothesis 2. To proxy for margin calls, we use changes in swap rates. We first examine the link between these swap rate changes and pension funds' fixed income holdings. Afterwards, we focus on large interest rate surges to study the selling behavior of specific fixed income securities in response to realized liquidity risk.

4.1 Feedback from Interest Rate Swaps to Asset Allocation

Starting with the first part of Hypothesis 2, we examine how changes in swap rates affect the asset allocation of pension funds in our sample. Throughout this section, we use the maximum ten-day change in a given month, computed as the maximum rolling change in the 20-year swap rate over a ten-day period (measured over business days) and show in the Internet Appendix (Table IA.4) that our results remain virtually unchanged when using monthly changes instead of the maximum 10-day changes. As discussed in Section 1.3, monthly security-level information is only available for 42 pension funds in our sample.

[18] One potential concern is that pension funds do not distinguish as clearly between cash-like assets and medium-term bonds. Hence, we repeat the analysis from Figure 6 replacing cash holdings with safe medium-term bond holdings. Similar to the results for cash holdings, Figure IA.7 in the Internet Appendix shows that pension funds with worse funding ratios tend to hold *less* safe medium-term bonds.

We run panel regressions of the following form:[19]

$$\frac{Net\ Buys_{i,t}}{AUM_{i,t-1}} = \beta_0 \Delta r_t^{Swap} + \beta_1 \Delta r_t^{Swap} \times Dur_{i,t-1}^{Swap} + \beta_2 Dur_{i,t-1}^{Swap} + \gamma C_{i,t-1} + \alpha_i + \varepsilon_{i,t}, \qquad (3)$$

where $\frac{Net\ Buys_{i,t}}{AUM_{i,t-1}}$ equals the net purchases (buys minus sales) of all fixed income assets by fund i at time t relative to its AUM at time $t-1$, Δr_t^{Swap} is the maximum ten-day change in the 20-year swap rate in period t, and $Dur_{i,t-1}^{Swap}$ is pension fund i's swap duration that captures their margin call risk at time $t-1$. $C_{i,t-1}$ captures time-varying fund-level controls and, building on the previous section, include fund i's lagged funding ratio, net contributions, required funding ratio, and liability duration.

In addition, to account for rebalancing effects in our analysis, we control for the relative performance of a fund's fixed income portfolio compared to its equity portfolio. Specifically, for each pension fund i, we calculate the change in the hypothetical allocation to fixed income if the fund did not conduct any trades at time t as follows:

$$\Delta w_{i,t}^{FI,hyp} = \frac{w_{i,t-1}^{FI}(1 + r_t^{IG})}{w_{i,t-1}^{FI}(1 + r_t^{IG}) + (1 - w_{i,t-1}^{FI})(1 + r_t^{MSCI})} - w_{i,t-1}^{FI}, \qquad (4)$$

where $w_{i,t-1}^{FI}$ equals the fixed income allocation of pension fund i at time $t-1$, r_t^{IG} the return on the European Investment Grade Bond Index at time t, and r_t^{MSCI} the return on the MSCI Index at time t. A positive value of Equation (4) indicates outperformance of the bond portfolio over the equity portfolio, leading to a mechanical increase in the fixed income allocation. Conversely, a negative value indicates underperformance of the bond portfolio, leading to a subsequent decrease in its allocation. To capture the potential delay in

[19]Because we now examine monthly instead of quarterly observations, and therefore a substantially larger time-series dimension, we cluster the standard errors in this part of the analysis at both the fund and time level.

rebalancing, our analysis includes both current and lagged (one and two months) hypothetical changes in the fixed income allocation. We include two lags to capture delayed rebalancing effects and note that including additional lags leaves our results virtually unchanged because higher lags are statistically insignificant.

Column (1) of Table 3 indicates a correlation between rising swap rates and net selling of pension funds' bond positions. A one standard deviation increase in the swap rate change (0.13%) corresponds with a 0.10% decrease in fixed income holdings. To gain additional insights, we replace changes in the 20-year swap rate with an indicator variable $\mathbb{1}\{\text{High}_t\}$ that equals one if there is a substantial (above the 90th percentile) increase in the 20-year swap rate in month t. As shown in Column (5) and consistent with larger margin calls during periods with notable spikes in swap rates, the economic impact is more pronounced. During periods of large rate increases, pension funds' fixed income allocations drop by 0.28%. In contrast to rebalancing due to the strategic asset allocation, which would imply that pension funds purchase fixed income securities when rates increase (and therefore bond prices decrease), this finding suggests that pension funds sell parts of their fixed income portfolio when swap rates rise.

[Insert Table 3 near here]

When contrasting our results with rebalancing because of the strategic asset allocation, it is important to note the difference in timing. If a pension fund faces a margin call, it must liquidate part of its fixed income portfolio immediately to fulfill its short-term liquidity need. By contrast, rebalancing after a shock to market prices occurs gradually and typically with a lag. Confirming this point and controlling for the rebalancing mechanism, Table 3 shows the expected patterns. The contemporaneous change in the hypothetical fixed income allocation is insignificant, while its lags are negative and statistically significant. Hence, higher bond returns induce pension funds to buy fixed income and move away from stocks in the next periods to keep the fraction of assets allocated to fixed income securities unchanged.

We next include an interaction term between changes in swap rates and the lagged swap duration of a given fund. The idea behind this test is that pension funds with larger swap durations are more exposed to margin calls and we would therefore expect a more significant effect of changes in swap rates on bond portfolios for funds with larger swap durations. In line with this view, Columns (2) and (6) show that the interaction term is statistically significant with the expected sign. By contrast, neither changes in the swap rate nor the indicator variable capturing interest rate surges are statistically significant. These cross-sectional results alleviate the potential concern that changes in swap rates are endogenous to pension funds' portfolio rebalancing.

To alleviate the concern that the selling behavior is driven by changes in pension funds' interest rate expectations, we next include the lagged bond duration of the pension fund's fixed income portfolio ($Dur^{Bond}_{i,t-1}$) and the corresponding bond duration interacted with changes in swap rates ($Dur^{Bond}_{i,t-1} \times \Delta r^{Swap}_t$) as control variables. Bond duration is a good first-order approximation of the return on pension funds' fixed income portfolio because, as shown in Table 1, the majority of pension funds' fixed income portfolios is in safe government debt (for which the major risk is interest rate risk). Moreover, controlling for the interaction between bond duration and rate changes mitigates the concern that fixed income sales are the result of changes in pension funds' interest rate expectations instead of margin calls.[20] To illustrate this point, suppose a pension fund expects worse future bond returns because

[20]One potential concern with including both bond and swap duration is multi-collinearity between the two variables. However, swap and bond duration are virtually uncorrelated as we illustrate in the Internet Appendix (Figure IA.6).

of further increases in interest rates. Suppose further that these expectations are positively correlated with the size of a pension fund's swap portfolio—for example, because further increases in interest rates result in larger losses on the swap portfolio for pension funds with more substantial swap positions. If this mechanism drives the selling behavior, we would expect a similar selling behavior among pension funds with long *bond* durations, as these funds are likewise more impacted by further interest rate increases, which would result in larger losses on their fixed income portfolios.

As shown in Columns (3) and (7), we find no relationship between a pension fund's bond duration and sales of fixed income securities when interest rates rise. This finding rules out the possibility that expectations of further rising interest rates, and consequently deteriorating bond returns, drive our results. To control for unobservable fluctuations in financial markets or the economy, we next add time-fixed effects as an additional control. These fixed effects absorb the time series variation in swap rates and we therefore focus on the interaction between changes in swap rates and lagged swap durations. As we observe from Columns (4) and (8), the effect of the interaction term remains virtually unchanged after controlling for time-fixed effects.

To further mitigate the concern that changes in swap rates are endogenous to pension funds' portfolio rebalancing, we instrument the ten-day changes in 20-year swap rates with the effect of monetary policy surprises (MPS) on the 20-year Euro OIS rates (Altavilla, Brugnolini, Gürkaynak, Motto, and Ragusa, 2019).[21] The rationale behind this test is that monetary policy surprises impact pension funds' portfolio decisions through their effect on swap rates, but these surprises are unlikely to directly affect pension funds' demand for bonds within the same month. These features ensure that both the relevance and exclusion

[21] The data starts in 2013M10, so our sample period for the IV is 2013M10-2022M12.

restriction of the IV are satisfied. Table IA.5 of the Internet Appendix summarizes the results. First, we note that the instrument is strong with a first stage t-stat varying between 8.94 and 76.53, well above the threshold of 4.05 suggested by Stock and Yogo (2005). In addition, our main conclusions remain unchanged: pension funds reduce bond holdings when swap rates rise, and this effect is driven by pension funds with large swap positions.

4.2 Selling Behavior During Interest Rate Surges

Moving on to the second part of Hypothesis 2, we now examine if pension funds first sell their most liquid securities in response to margin calls. Recall from Section 1.4 that we focus on months in which the maximum ten-day change in swap rates exceeds 40 basis points to capture margin calls. We list these eight event months and the associated movements in swap rates in Table A1.

Prior to selling bonds, it is plausible that pension funds use their cash buffers to fulfill margin calls. While our monthly data does not include detailed information on actual cash holdings (e.g., bank deposits), we observe monthly Money Market Fund (MMF) holdings. MMFs are cash-like securities and part of the quarterly cash definition presented in Figure 3.

Figure IA.5 of the Internet Appendix confirms that pension funds sell their MMF shares during periods of substantial increases in interest rates. This finding aligns with Ghio et al. (2023), who demonstrate that MMF outflows in March 2020 were driven by investors facing substantial margin calls on their interest rate derivative portfolios. Additionally, a recent stress-test indicates that Dutch pension funds identify the sales of MMF shares as a key strategy for obtaining liquidity (DNB and AFM, 2024).[22] However, as the median pension

[22] Pension funds may also obtain short-term liquidity through the repo market. In our data, it is easy to differentiate between sales and repo agreements because a bond sold outright is removed from the fund's balance sheet, whereas a bond pledged as collateral in a repo transaction remains.

fund holds less than 1.5% in MMFs, the sales of MMFs (and other cash-like assets) are insufficient to cover the margin calls in these periods. Hence, we next examine the selling of bonds in response to margin calls.

Our hypothesis is that the selling is concentrated within the safest and most liquid bonds. To test this hypothesis, we introduce an indicator variable $\mathbb{1}\{\text{AAA}\}_{j,t}$ that equals one if security j is a Euro-denominated government bond with a triple-A rating from all three major rating agencies and has a remaining time to maturity above one year in period t. We exclude non-Euro-denominated safe government bonds because the margin calls are for Euro-denominated swaps and therefore liquidating non-Euro-denominated bonds exposes pension funds to additional currency risk. During our sample period, only Dutch and German government bonds held a triple-A rating from major agencies (see Table IA.7 in the Internet Appendix for an overview of the credit ratings in our sample). In addition, we exclude bonds with remaining time to maturity below one year to clearly distinguish safe euro-bonds from cash-like assets.[23] Furthermore, since medium-term bonds are more liquid than long-term bonds, we expect selling to be concentrated at the medium-term of the maturity spectrum. Hence, we introduce an indicator variable $\mathbb{1}\{T < 7\}_{j,t}$ that equals one if the bond has a remaining time to maturity that is less than seven years.

To understand which parts of their fixed income portfolios pension funds liquidate when they face margin calls, we examine security-level changes in the *notional* amounts for each fund in each of the eight event months.[24] As a starting point of our analysis, we compare the percentage changes in the notional amount of triple-A Euro-denominated bonds to the

[23]Including safe bonds with less than one year to maturity leads to a marginal increase in the economic significance of our results. For instance, after including one-year bonds, the coefficients reported in Columns (1) to (3) of Table 4 range from -0.074 to -0.094 instead of -0.061 to -0.086.

[24]Focusing on notional amounts rather than market values ensures that our results are not influenced by price dynamics.

percentage changes of all debt for each fund in our sample. As shown in Figure 7, we observe larger declines in holdings for triple-A rated Euro-denominated bonds compared to other bonds.

[Insert Figure 7 near here]

We next run panel regressions of the following form:

$$\Delta\%Hold_{i,j,t} = \beta Dur^{Swap}_{i,t-1} \times \mathbb{1}\{\text{AAA}\}_{j,t} \times \mathbb{1}\{T < 7\}_{j,t} + \gamma C_{i,j,t} + \delta_j + \alpha_{i,t} + \varepsilon_{i,j,t}, \quad (5)$$

where $\Delta\%Hold_{i,j,t}$ captures the percentage change of the holding of fund i in security j, measured over each surge month t, and $Dur^{Swap}_{i,t-1}$ is the duration of the swap portfolio of fund i in the previous month $t-1$. $C_{i,j,t}$ includes the interaction terms between the two indicators and with lagged swap duration separately, δ_j are security-fixed effects, and $\alpha_{i,t}$ are fund-time fixed effects.[25] This specification allows us to test if pension funds with a higher exposure to margin calls sell more of their liquid assets.

Starting with a specification that only interacts the lagged swap duration with the triple-A indicator, Column (1) of Table 4 shows that sales of triple-A rated government bonds are more pronounced for funds with larger swap durations. Further examining this result, Column (2) shows that the regression coefficient remains virtually unchanged when adding time-fixed effects. Similarly, Column (3) shows that adding both fund-time and security fixed effects leaves our inference unchanged. To show that the sales of triple-A bonds are concentrated at the medium-term of the maturity spectrum, we also examine the interaction

[25] We cluster the standard errors in this regression at the security level to allow for correlation in the error term across pension funds for a given security. The coefficient β remains statistically significant if we double cluster at the fund and security level (also allowing for correlation in the error term across securities within a pension fund).

with $\mathbb{1}\{T < 7\}_{j,t}$ in Columns (4) to (6). We find that this triple interaction term is significant across all specifications at the 1%-significance level, while the interaction between the lagged swap duration and the triple-A indicator becomes insignificant. In terms of economic magnitude, a one standard deviation increase in the swap duration (5.71) lowers the individual holdings of triple-A Euro-denominated bonds with less than seven years to maturity by -0.84% ($= 5.71 \times -0.147$).

[Insert Table 4 near here]

The finding that pension funds mostly sell medium-term bonds when interest rates rise contradicts the idea that they intentionally reduce the duration of their fixed income portfolios. As interest rates rise, the duration of their liabilities decreases. If pension funds were to reduce the duration of their assets at the same time, they would sell long-term instead of medium-term bonds.

We perform two robustness checks for our analysis. First, we repeat our analysis using realized margin calls instead of our proxy. As shown in the Appendix (Table A2), the results remain largely unchanged when focusing on the realized margin calls and the events where this measure is available.[26] Second, as in Section 4.1 before, we next use the MPS on the 20-year Euro OIS rate from Altavilla et al. (2019) to conduct additional tests that alleviate the potential concern that changes in swap rates are endogenous to pension funds' selling behavior. In these tests, we repeat our analysis focusing on months with both interest rate surges and a positive effect of MPS on the 20-year Euro OIS rate. The idea behind focusing on these months is that the rate surges are linked to (surprising) changes in monetary policy. By conditioning on both months with substantial interest rate increases and positive MPS

[26] The coefficient estimates in Table A2 are about twice as large compared to those in Table 4. The reason for this difference is that the average realized margin call in this sample is 4.5 compared to the average swap duration of 9.5.

on the 20-year OIS rates, we obtain four event months: 2015M6 (7.5 basis points), 2022M4 (1.9 basis points), 2022M9 (2.4 basis points), and 2022M12 (8.5 basis points). This test constitutes a subsample-analysis and we report the results of these additional tests in the Internet Appendix (Table IA.6). Focusing on this subset of event months with positive MPS leaves our main results unchanged.

4.2.1 Equity and Illiquid Bond Sales in Response to Margin Calls?

For equities, we note a qualitative difference between the eight periods of interest rate surges. The rate increases in 2022 mark a persistent change in monetary policy, while the increases in 2015 and 2020 are transitory spikes. Persistent increases in interest rates lower the value of pension funds' fixed income portfolios and give them an incentive to rebalance their portfolios by selling equities. This rebalancing can occur independently of margin calls.

[**Insert Figure 8 near here**]

Figure 8 illustrates the qualitative differences in the eight rate surge episodes. While pension funds sell parts of their bond portfolios during all episodes, equity sales are unique to the rate increases in 2022.[27] These findings suggest that the equity sales in 2022 occurred because of portfolio rebalancing. In the absence of margin calls, pension funds would use the proceeds from equity sales to increase their bond holdings. In 2022, during persistent surges in interest rates, it is plausible that pension funds used parts of their equity proceeds to accommodate margin calls. A similar rebalancing channel for covering margin calls is proposed by EIOPA (2023). Hence, our findings represent a conservative estimate compared to a scenario in which pension funds did not hold equities. Indeed, UK pension funds have

[27] We detrend the cumulative distributions of net buys to remove the effect of pension funds growing, and hence buying more assets over time.

significantly lower equity allocations than their Dutch counterparts.[28] This difference likely contributed to the more pronounced sell-off and price impact in the UK gilt market observed in September and October 2022.

For illiquid bonds, an interesting question is if pension funds also sold these bonds in response to margin calls. Such sales might lead to an even bigger price impact than their sales of liquid bonds (Ellul et al., 2022). We investigate this possibility in the Appendix (Table A3). To that end, we first obtain bid-ask spreads for the bonds in our sample from Eikon and then classify illiquid bonds as those with bid-ask spreads in the 80th percentile.[29] As in Equation (5), we then interact this indicator with the lagged swap duration. In contrast to liquid bonds, we do not find any significant sales of illiquid bonds during months with substantial interest rate rises.

5 Price Impact of Pension Funds

Because Dutch pension funds are large investors in the safe Euro-denominated government bond market (e.g., Jansen, 2024), our third hypothesis is that their bond sales due to margin calls have an adverse price impact. We first show that bonds which are more likely sold by pension funds in response to margin calls experience larger price drops during periods of interest rate surges. Afterwards, we use a GIV approach to examine the aggregate effect of margin calls on safe Euro bond yields.

[28] UK pension funds on average allocate 10-15% to equities (`https://www.chicagofed.org/publications/chicago-fed-letter/2023/480`), compared to 33% for Dutch pension funds (Table 1).

[29] Results remain qualitatively similar if we focus on the 90th percentile.

5.1 Cross-Sectional Bond Price Effects

To test Hypothesis 3, we construct a bond-level measure of margin call risk for bond b:

$$MC_t^b = \sum_{i=1}^{K_t^b} Dur_{i,t}^{Swap} \frac{N_{i,t}^b}{\sum_{k=1}^{K_t^b} N_{k,t}^b}, \tag{6}$$

where $Dur_{i,t}^{Swap}$ is the swap duration of pension fund i in quarter t, $N_{i,t}^b$ is the notional amount of bond b held by fund i in month t, and K_t^b captures the number of funds that hold bond b at time t. Inspired by Ma et al. (2022), this measure captures the weighted margin call risk for bond b.

Given the results from the previous section, we focus our analysis of price impact on German and Dutch government bonds with less than seven years to maturity. We obtain issuance-level information for all German and Dutch government bonds from the respective auction schedules. For each bond, we then obtain daily (clean) mid-market prices from Thomson Reuters Eikon and compute bond returns during the ten-day periods of substantial increases in swap rates.

Figure 9 shows a binned scatter plot of our bond-level measure of margin call risk against the ten-day returns of medium-term bonds ($T < 7$) that are orthogonal to the component of returns driven by time-to-maturity. The graph illustrates a clear negative correlation between our margin call risk measure and bond returns: bonds that exhibit higher exposure to margin call risk tend to have lower maturity-adjusted returns during periods of interest rate surges.

[Insert Figure 9 near here]

To test the price impact more formally, we run regressions of the following form:

$$r_t^b = \alpha + \beta MC_{t-1}^b + \gamma C_t^b + \varepsilon_t^b, \tag{7}$$

where r_t^b is the ten-day percentage change in the clean price of bond b, MC_{t-1}^b is our margin call risk measure for bond b measured the month before the start of the ten-day price change, and C_t^b are bond-level controls including time-to-maturity, time-to-maturity squared (to capture convexity), time since issuance (age), coupon rate, log total outstanding volume, indicator variable that equals one if the bond is inflation-linked, and an indicator variable that equals one if the bond is issued by the Netherlands.

Column (1) of Table 5 shows that the ten-day returns of bonds exposed to pension funds with higher margin call risk are significantly lower than the returns of other bonds. As shown in Column (2), this result remains virtually unchanged when we control for year-to-maturity fixed effects, indicating that our results are robust to second order effects such as curvature. In terms of economic magnitude, a one standard deviation increase in the margin call risk measure (= 4.50) reduces bond returns by 5.5 basis points, or 8.5% of the average return (= −0.65%) during periods of substantial interest rate increases. As an additional test, we reconstruct MC_t^b by replacing $Dur_{i,t}^{Swap}$ in Equation (6) with realized margin calls (which are available form 2018 onward). Columns (3) and (4) of Table 5 show that we obtain similar results when using realized instead of estimated margin calls.

[Insert Table 5 near here]

We next investigate if the results in Columns (1) and (2) are indeed due to the heterogeneous exposure of the bonds to margin call risk from the pension funds. To that end, we construct a counterfactual variable that simply captures the equally weighted swap duration of the pension funds holding the bond:

$$CF_t^b = \frac{1}{K_t^b} \sum_{i=1}^{K_t^b} Dur_{i,t}^{Swap}. \tag{8}$$

CF_t captures the average swap duration of all pension funds holding a given bond, which does not necessarily reflect the margin call risk of the bond. This variable differs significantly from MC_t because of the large cross-sectional variation in swap exposures and position sizes across pension funds. In particular, the correlation between CF_t and MC_t is only 0.55. Hence, we would expect weaker results using the counterfactual measure. In line with our expectations, Columns (3) and (4) show no significant link between bond returns and the counterfactual measure.

As margin calls create temporary price pressure on bonds, it is interesting to study if we observe price reversals in the affected bonds. We examine this question in the Appendix, focusing on the rate surge in March 2020.[30] Figure A3 shows the cumulative returns of bonds most and least affected by margin calls, as measured by the 80th and 20th percentile of the margin call risk measure, respectively. The figure highlights a clear price reversal after approximately 50 days.

5.2 Granular Instrumental Variables Approach

After demonstrating the effect of bond-specific margin call risk on bond prices, we next estimate the aggregate price sensitivity of safe Euro government bonds to sales by pension funds,

[30] Addressing price reversals is challenging in our setting because rate surges in our sample often follow each other, making it difficult to define a clear post-period. We therefore focus on March 2020 in this part of our analysis. The March 2020 episode was marked by a temporary spike in interest rates, providing the additional advantage that pension funds were unlikely to rebalance due to strategic asset allocation, thereby reducing the risk of mechanically induced price reversals.

using the Granular Instrumental Variables (GIV) approach developed by Gabaix and Koijen (2024). As discussed by Ma et al. (2022), this is a useful addition to the cross-sectional analysis, which removes any common effect on bond yields. To obtain granular bond holdings, we expand our monthly data of Dutch pension funds by including Dutch insurance companies, mutual funds, and banks at the institution level in the sample.[31] We supplement these data with monthly holdings of international mutual funds from Morningstar. This expanded sample captures 2,214 institutions that jointly hold, on average, 12% of all outstanding safe Euro debt. Figure IA.9 in the Internet Appendix shows the coverage over time.

To apply the GIV procedure, we draw on Ma et al. (2022), who use a similar approach for US Treasuries. In a first step, we focus on percentage changes in the holdings of investor i ($\Delta q_{i,t}$). We winsorize these changes in holdings at the 1% level to avoid outliers driving our findings. To extract idiosyncratic shocks to these holdings, we run weighted regressions of the following form:[32]

$$\Delta q_{i,t} = \alpha_t + \alpha_i + \beta_{0,i} GDPgrowth_t + \beta_{1,i} \Delta Inflation_t + \beta_{2,i} \Delta Fiscal_t + \beta_{3,i} t + \Delta \check{q}_{i,t}. \quad (9)$$

In these regressions, we control for time- and investor-fixed effects. In addition, we add GDP growth, changes in (CPI) inflation, changes in fiscal capacity (measured as net lending relative to GDP), and a time trend as controls, allowing the coefficient loadings to vary across investors. To compute the macro variables, we take value-weighted averages between the Dutch and German counterparts, using their respective total debt outstanding as weights.

Because our holdings data are monthly and we only observe quarterly GDP and inflation,

[31] Dutch institutions report their security holdings to DNB on a monthly basis. DNB gathers these data to compute, among other things, the Dutch balance of payments, international investment positions, and the financial accounts.

[32] The weights are $E_i = \frac{\sigma_i^{-2}}{\sum_k \sigma_k^{-2}}$, where σ_i is the volatility in holdings of investor i.

we estimate GDP growth (inflation changes) by allocating one-third of the growth (changes) in quarter t to each of the three months within quarter t. As we observe the fiscal capacity only annually, we take it with a one year lag to avoid look-ahead bias. We obtain the idiosyncratic demand shocks $\Delta\check{q}_{i,t}$ from regression (9). Our instrument Z_t is the weighted sum of these shocks, weighing shock i by the share of outstanding government bonds held by investor i. Figure IA.9 in the Internet Appendix shows our instrument over time.

In the second step, we use the instrument to estimate the elasticity M of yield changes to a one percent inflow in government debt by running time-series regressions of the following form:

$$\begin{aligned}\Delta y_t^3 &= MZ_t + \gamma_0 GDPgrowth_t + \gamma_1 \Delta Inflation_t + \gamma_2 \Delta Fiscal_t \\ &+ \lambda_1 PC_{1,t} + \lambda_2 PC_{2,t} + \lambda_3 PC_{3,t} + \alpha + \varepsilon_t. \end{aligned} \tag{10}$$

The dependent variable is the 3-year safe Euro government bond yield, computed as the value-weighted average of the 3-year Dutch and German yields, again using the respective outstanding debt as weights. We control for GDP growth, changes in inflation, and changes in fiscal capacity. Additionally, we control for the first ($PC_{1,t}$), second ($PC_{2,t}$), and third ($PC_{3,t}$) principal components of the idiosyncratic changes in holdings to capture any common comovements in holdings that may affect yields.

Table 6 shows the results of the GIV. Columns (1) to (5) show that using idiosyncratic changes in investor holdings allows us to detect the impact of demand on bond yields. Across specifications we find that a 1% inflow into the safe Euro debt market reduces the 3-year yield by 14.2 basis points. This estimate is of comparable magnitude to the GIV estimates of Ma et al. (2022), who find that a 1% inflow into US Treasuries decreases the 20-year yield by 8.7 basis points. This result remains virtually unchanged when controlling for two or three of the principal components.

[Insert Table 6 near here]

To better understand the economic magnitude of our results, we link the GIV estimates to the price pressure resulting from margin calls. For instance, during August 2022, pension funds sold €11.13 billion of their total safe government bond portfolio, which translates into 0.61% of the total debt outstanding. Hence, this selling because of margin calls increased the safe Euro 3-year yield by 8.7 basis points. During the same point, the 3-year yield went up by 87 basis points, so the selling behavior of pension funds contributed 10% to the total increase.

6 Conclusion

Pension funds use interest rate swaps to hedge the interest rate risk of their liabilities while investing substantial parts of their portfolio in securities with higher expected returns, such as stocks. While this hedging behavior benefits plan participants by (i) reducing interest rate risk and (ii) generating higher expected returns, we highlight in this paper that the use of interest rate swaps exposes pension funds to substantial liquidity risk. When interest rates increase and the present value of their swap positions drops, pension funds face margin calls that can exceed 10% of their total AUM. In response to these margin calls, pension funds sell safe government bonds with medium-term maturities. This procyclical selling behavior of selling parts of their bond portfolio when bond prices fall has an adverse price impact and exposes pension funds to market liquidity risk.

Our results challenge the traditional view that pension funds are stable long-term investors immune to liquidity risk and provide relevant policy implications. *Pension liquidity risk* arises as an unintended consequence of a combination of two financial regulations designed to enhance market stability: (i) Capital requirements for DB pension funds and (ii) collateral requirements for interest rate swaps. Given that interest rate swaps are a valuable hedging tool for pension funds, one potential policy implication of our analysis is to incorporate capital requirements for liquidity risk and introduce "liquidity stress tests" into pension regulation. These regulations should not curb interest rate swap usage per se, but reduce the liquidity risk associated with using swap contracts and avoid scenarios in which pension funds face margin calls that substantially exceed their available cash positions.

References

Adams, J. and D. J. Smith (2009). Mind the gap: Using derivatives overlays to hedge pension duration. *Financial Analysts Journal 65*(4), 60–67.

Aldunate, F., Z. Da, B. Larrain, and C. Sialm (2023). Pension fund flows, exchange rates, and covered interest rate parity. Working paper, University of Texas Austin.

Alfaro, L., S. Bahaj, R. Czech, J. Hazell, and I. Neamțu (2024). Lash risk and interest rates. Work in progress.

Altavilla, C., L. Brugnolini, R. S. Gürkaynak, R. Motto, and G. Ragusa (2019). Measuring euro area monetary policy. *Journal of Monetary Economics 108*, 162–179.

Andersson, M. (2023). The liquidity crisis in UK pension funds from a Swedish perspective. Staff memo, Sveriges Riskbank.

Andonov, A., R. Bauer, and M. Cremers (2017). Pension fund asset allocation and liability discount rates. *Review of Financial Studies 30*(8), 2555–2595.

Ang, A., B. Chen, and S. M. Sundaresan (2012). Liability driven investment with downside risk. *Netspar Discussion Paper*.

Angrist, J. D. and J.-S. Pischke (2009). *Mostly harmless econometrics: An empiricist's companion*. Princeton university press.

BCBS and IOSCO (2015). Margin requirements for non-centrally cleared derivatives. Technical report, Bank for International Settlements.

Ben-David, I., F. Franzoni, and R. Moussawi (2012). Hedge fund stock trading in the financial crisis of 2007–2009. *Review of Financial Studies 25*(1), 1–54.

Boon, L., M. Brière, and S. Rigot (2018). Regulation and pension fund risk-taking. *Journal of International Money and Finance 84*, 23–41.

Brunnermeier, M. K. and L. H. Pedersen (2009). Market liquidity and funding liquidity. *The Review of Financial Studies 22*(6), 2201–2238.

Cenedese, G., A. Ranaldo, and M. Vasios (2020). OTC premia. *Journal of Financial Economics 136*(1), 86–105.

Chang, Y., H. Hong, and I. Liskovich (2015). Regression discontinuity and the price effects of stock market indexing. *Review of Financial Studies 28*, 212–246.

Chodorow-Reich, G., A. Ghent, and V. Haddad (2021). Asset insulators. *The Review of Financial Studies 34*(3), 1509–1539.

Chordia, T., A. Sarkar, and A. Subrahmanyam (2005). An empirical analysis of stock and bond market liquidity. *The Review of Financial Studies 18*(1), 85–129.

Czech, R., S. Huang, D. Lou, and T. Wang (2021). An unintended consequence of holding dollar assets. Working paper, Bank of England.

Da, Z., B. Larrain, C. Sialm, and J. Tessada (2018). Destabilizing financial advice: Evidence from pension fund reallocations. *The Review of Financial Studies 31*(10), 3720–3755.

DNB and AFM (2024). Liquiditeitsrisico's derivaten pensioenfondsen onder verschillende stress scenario's. De Nederlandsche Bank en Autoriteit Financiële Markten.

Domanski, D., H. Shin, and V. Sushko (2017). The hunt for duration: Not waving but drowning? *IMF Economic Review 65*(1), 113–153.

ECB (2022). Euro area pension fund statistics: fourth quarter of 2021. Technical report, European Central Bank.

EIOPA (2017). Technical documentation of the methodology to derive eiopa's risk-free interest rate term structures. Technical report, European Insurance and Occupational Pensions Authority.

EIOPA (2022). Financial stability report December 2022. Technical report, European Insurance and Occupational Pensions Authority.

EIOPA (2023). Financial stability report December 2023. Technical report, European Insurance and Occupational Pensions Authority.

Ellul, A., C. Jotikasthira, A. V. Kartasheva, C. T. Lundblad, and W. Wagner (2022). Insurers as asset managers and systemic risk. *Review of Financial Studies 35*, 5483–5534.

Ellul, A., C. Jotikasthira, and C. Lundblad (2011). Regulatory pressure and fire sales in the corporate bond market. *Journal of Financial Economics 101*, 596–620.

ESMA (2022). Clearing obligation for pension scheme arrangements. Technical report, European Securities and Markets Authority.

European Parliament and Council (2012). Regulation (EU) no 648/2012 of the European Parliament and of the Council of 4 July 2012 on OTC derivatives, central counterparties and trade repositories (EMIR) (article 11).

Fabozzi, T. D., T. Tong, and Y. Zhu (1990). Symmetric cash matching. *Financial Analysts Journal 46*(5), 46–52.

Gabaix, X. and R. S. Koijen (2022). In search of the origins of financial fluctuations: The inelastic markets hypothesis. Working paper, National Bureau of Economic Research.

Gabaix, X. and R. S. Koijen (2024). Granular instrumental variables. *Journal of Political Economy* Forthcoming.

Ge, S. and M. S. Weisbach (2021). The role of financial conditions in portfolio choices: The case of insurers. *Journal of Financial Economics 142*(2), 803–830.

Ghio, M., L. Rousova, D. Salakhova, and M. G. V. Bauer (2023). Derivative margin calls: A new driver of MMF flows. International Monetary Fund.

Greenwood, R. (2005). Short-and long-term demand curves for stocks: Theory and evidence on the dynamics of arbitrage. *Journal of Financial Economics 75*(3), 607–649.

Greenwood, R. and D. Vayanos (2010). Price pressure in the government bond market. *American Economic Review: Papers and Proceedings 100*, 585–590.

Greenwood, R. and A. Vissing-Jorgensen (2018). The impact of pensions and insurance on global yield curves. Working paper, Harvard Business School.

Grinblatt, M. and M. Keloharju (2000). The investment behavior and performance of various investor types: A study of Finland's unique data set. *Journal of financial economics 55*(1), 43–67.

IMF (2023). Non-bank financial intermediaries vulnerabilities amid tighter financial conditions. *IMF Global Financial Stability Report, Chapter 2*.

ISDA (2017). International swaps and derivatives association margin survey. Technical report, International Swaps and Derivatives Association.

Jansen, K. A. E. (2024). Long-term investors, demand shifts, and yields. *The Review of Financial Studies* Forthcoming.

Jiang, H., Y. Li, Z. Sun, and A. Wang (2022). Does mutual fund illiquidity introduce fragility into asset prices? Evidence from the corporate bond market. *Journal of Financial Economics 143*(1), 277–302.

Khetan, U., J. Li, I. Neamtu, and I. Sen (2023). The market for sharing interest rate risk: Quantities and asset prices. Working papers, Harvard Business School.

Klingler, S. and S. Sundaresan (2019). An explanation of negative swap spreads: Demand for duration from underfunded pension plans. *Journal of Finance 74*(2), 675–710.

Koijen, R. and M. Yogo (2019). A demand system approach to asset pricing. *Journal of Political Economy 127*(4), 1475–1515.

Koijen, R. S. and M. Yogo (2021). The evolution from life insurance to financial engineering. *The Geneva Risk and Insurance Review 46*(2), 89–111.

Koijen, R. S. and M. Yogo (2022). Global life insurers during a low interest rate environment. In *AEA Papers and Proceedings*, Volume 112, pp. 503–508. American Economic Association 2014 Broadway, Suite 305, Nashville, TN 37203.

Leibowitz, M. L. (1986). The dedicated bond portfolio in pension funds—part i: Motivations and basics. *Financial Analysts Journal 42*(1), 68–75.

Ma, Y., K. Xiao, and Y. Zeng (2022). Mutual fund liquidity transformation and reverse flight to liquidity. *Review of Financial Studies 35*(10), 4674–4711.

Manconi, A., M. Massa, and A. Yasuda (2012). The role of institutional investors in propagating the crisis of 2007–2008. *Journal of Financial Economics 104*(3), 491–518.

Meyer, J., C. M. Reinhart, and C. Trebesch (2022, 01). Sovereign Bonds Since Waterloo. *The Quarterly Journal of Economics 137*(3), 1615–1680.

OECD (2022). Pension markets in focus 2022. Technical report, Organization for Economic Cooperation and Development.

O'Sullivan, C. and V. G. Papavassiliou (2020). On the term structure of liquidity in the European sovereign bond market. *Journal of Banking & Finance 114*, 105777.

Pinter, G. (2023). An anatomy of the 2022 Gilt market crisis. Working paper, Bank of England.

Pinter, G., E. Siriwardane, and D. Walker (2024). Fire sales of safe assets. *Available at SSRN 4839251*.

Scholes, M. (2000). Crisis and risk management. *American Economic Review 90*, 17–21.

Sen, I. (2023). Regulatory limits to risk management. *The Review of Financial Studies 36*(6), 2175–2223.

Shleifer, A. (1986). Do demand curves for stocks slope down? *The Journal of Finance 41*(3), 579–590.

Stock, J., J. Wright, and M. Yogo (2002). A survey of weak instruments and weak identification in generalized method of moments. *Journal of Business and Economic Statistics 20*, 518–529.

Stock, J. H. and M. Yogo (2005). Testing for weak instruments in linear IV regression. In *Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg*, Chapter 5. Cambridge: Cambridge Univ. Press.

Timmer, Y. (2018). Cyclical investment behavior across financial institutions. *Journal of Financial Economics 129*, 268–286.

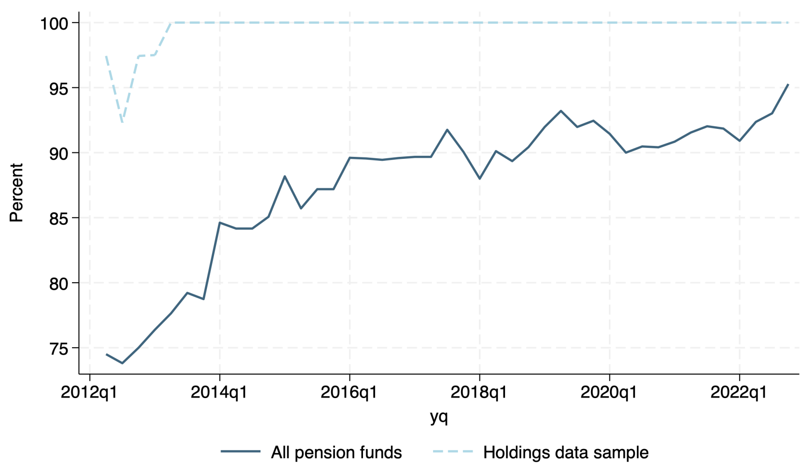
U.K. Parliament (2022). Financial markets stability: Volume 825: debated on thursday 3 november 2022. Technical report.

Wurgler, J. and E. Zhuravskaya (2002). Does arbitrage flatten demand curves for stocks? *The Journal of Business 75*(4), 583–608.

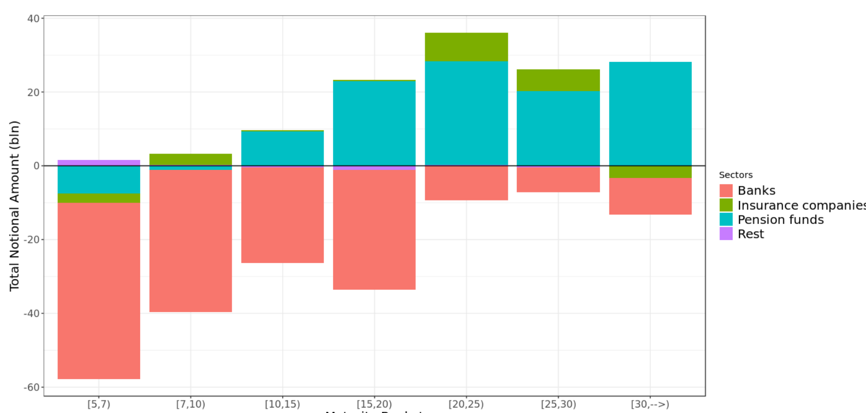
Figures and Tables

Figure 1: **The size of pension funds in the swap market**

Panel (a) shows the fraction of total pension funds that uses swaps over time, both for the full sample of pension funds (blue solid line) and for the sample of pension funds that report holdings data (light blue dashed line). The quarterly sample period is 2012Q1-2022Q4. Panel (b) shows the net notional amount in Euribor interest rate swaps for different maturity buckets for banks, pension funds, insurance companies, and the rest established in the Netherlands. The data source is the EMIR database and calculations are based on the average week-day positions over the year 2020.



(a) Swap usage by Dutch pension funds



(b) Net notional Euribor swaps Dutch counterparties

Figure 2: **The duration of pension funds' liabilities and portfolios**

This graph shows the cross-sectional average duration of the liabilities (green dashed line), long-only assets (blue solid line), and total portfolio (purple dashed line) over time. The total portfolio duration equals the sum of the asset and swap duration. The quarterly sample period is 2012Q1-2022Q4.

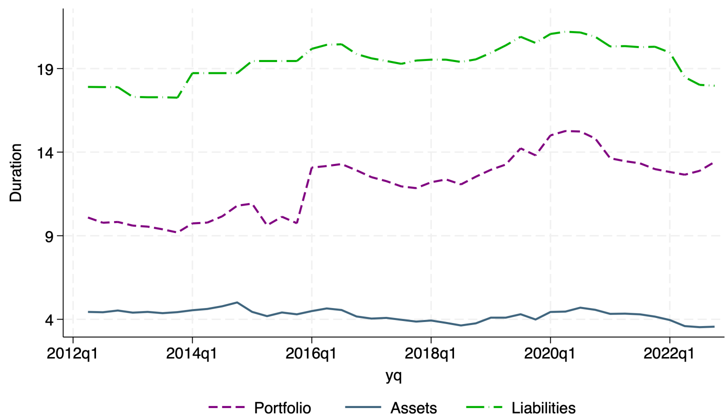
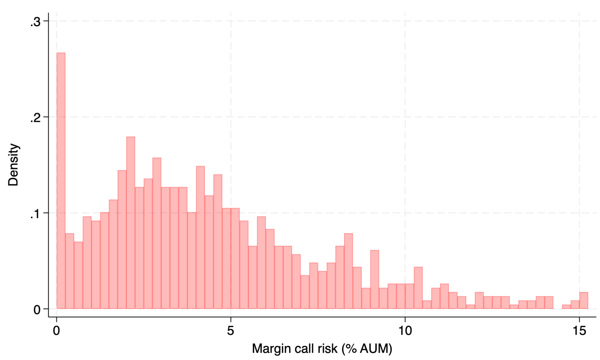
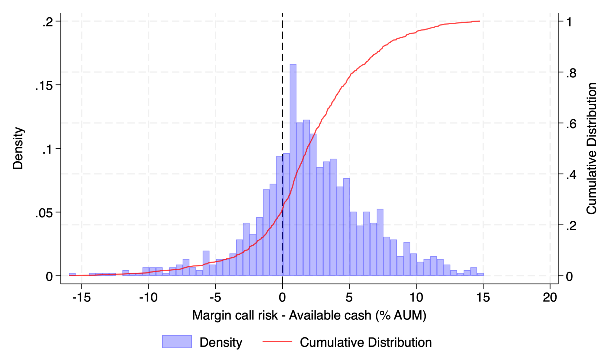


Figure 3: **Margin call risk versus available cash**

Panel (a) shows the distribution of realized margin calls as a fraction of AUM for each pension fund during periods of interest rate surges (2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12). Panel (b) shows the (cumulative) distribution of realized margin calls minus available cash relative to AUM for each pension fund during periods of interest rate surges. The realized margin call risk equals the lagged swap duration times the maximum realized 10-day change in the 20-year swap rate. Available cash includes money market funds, as well as short-term bonds and (term) deposits with initial maturities of less than one year.



(a) Realized margin calls



(b) Realized margin calls minus available cash

Figure 4: **Margin call risk versus changes in funding ratios**

This figure provides a scatter plot of the realized margin calls and the changes in funding status, both as a fraction of AUM, for each pension fund during periods of interest rate surges (2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12). The realized margin call risk equals the lagged swap duration times the maximum realized 10-day change in the 20-year swap rate. The changes in funding ratios are computed as the change in the assets minus liabilities from the quarter starting prior to the swap rate rise to the quarter after.

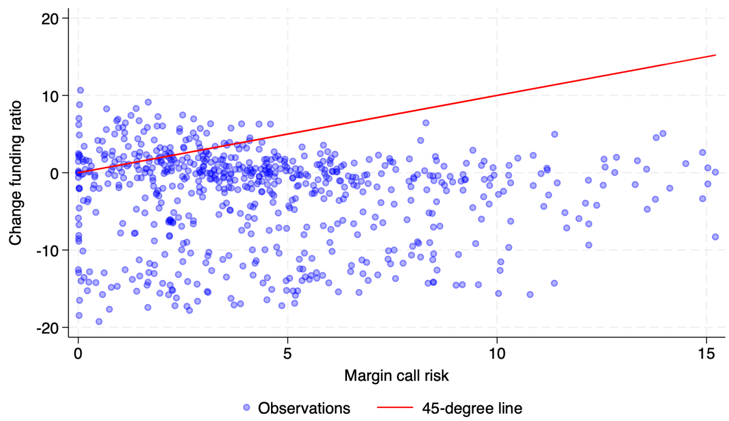


Figure 5: **Portfolio duration and lagged funding ratio**

This graph shows a bin-scatter plot of the lagged funding ratio against the total portfolio duration. Each dot represents a group of pension fund-quarter observations, whereby we split pension fund-quarter observations in $\sqrt{N} = 89$ groups. The durations are in years and the quarterly sample period is 2012Q1-2022Q4.

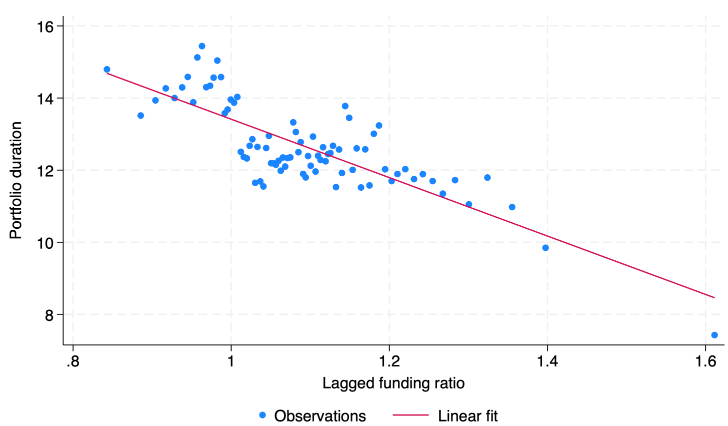


Figure 6: **Cash allocation and the funding ratio**

This graph shows a bin-scatter plot of the lagged funding ratio against the allocation to cash. Each dot represents a group of pension fund-quarter observations, whereby we split pension fund-quarter observations in $\sqrt{N} = 73$ groups. The cash allocation is in percentage points and the quarterly sample period is 2015Q1-2022Q4 (cash allocations are only reported as of 2015Q1).

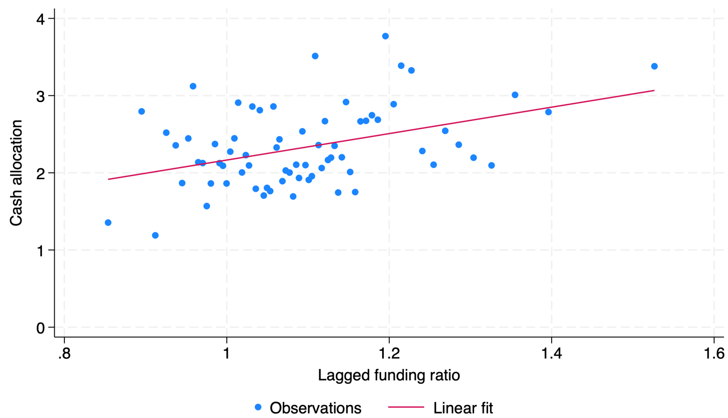


Figure 7: **Changes in bond holdings during periods of interest rate surges**

This graph shows the percentage change in nominal bond holdings during periods of interest rate surges: 2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12 separately for AAA Euro-denominated government bonds (red bars) and the the total bond portfolio (blue bars).

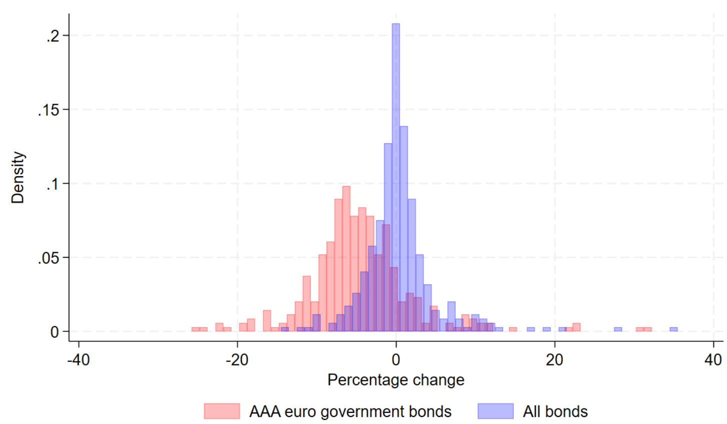
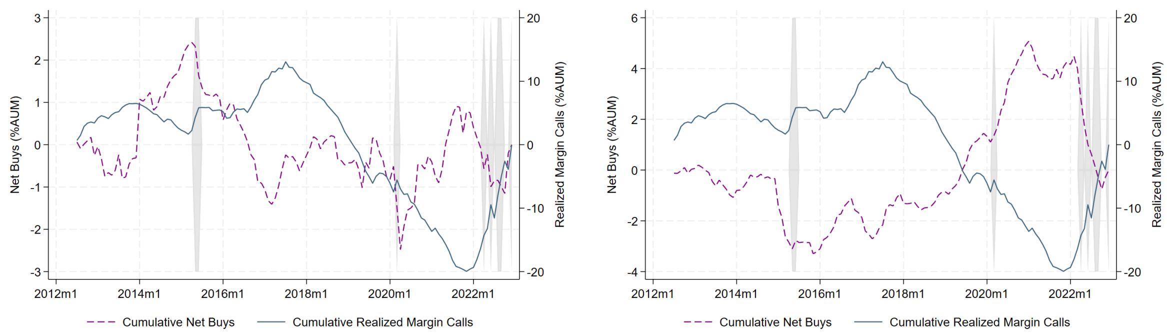


Figure 8: **Cumulative fixed income versus equity sales**

This figure plots the detrended cumulative distribution of aggregate net buys (relative to AUM) against the detrended cumulative distribution of aggregate realized margin calls for fixed income in Panel (a) and equities in Panel (b). Net buys is defined as the total purchases minus sales of fixed income (equities) securities, both at market values and aggregated across pension funds. The realized margin call risk equals the value-weighted lagged swap duration across pension funds, times the maximum realized 10-day change in the 20-year swap rate. The monthly sample period is 2012M1-2022M12.



(a) Fixed Income

(b) Equities

Figure 9: **Margin call risk exposure and bond returns**

This graph plots our measure of margin call exposure at the bond-level against the bond returns during the 10-day window of maximum 20-year swap rate changes for bonds with remaining time to maturities below 7 years, orthogonal to the component of returns driven by time-to-maturity. We include all periods of interest rate surges: 2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12. Each dot represents a group of bond-month observations, whereby we split pension bond-month observations in $\sqrt{N} = 23$ groups.

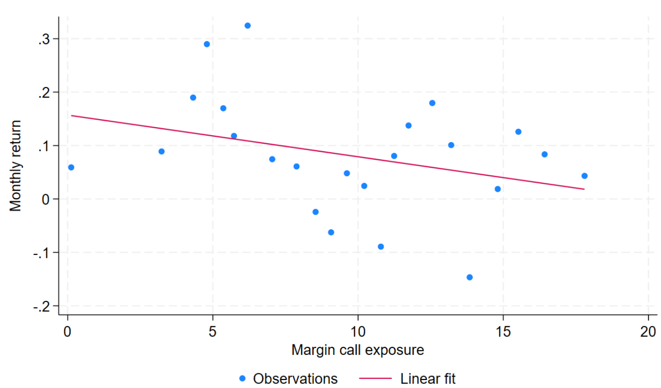


Table 1: **Summary statistics**: Panel A shows the AUM (billions), funding ratio (pp), required funding ratio (pp), net contributions (% AUM), allocation to fixed income (pp), allocation to cash (pp), allocation to equities (pp), and duration of the liabilities, total portfolio, assets, and swaps (years). Cash includes money market funds and deposits with less than one year maturities. Panel B reports summary statistics on the bond holdings data to geographies and bond types (% total bond holdings). Panel C summarizes the market data (pp, annualized). The cross-sectional mean, standard deviation, median, 5th percentile, and 95th percentile are reported. Panel A is based on quarterly data between 2012Q1-2022Q4 and Panel B and C are based on monthly data from 2012M1-2022M12.

Panel A: Quarterly Regulatory Data

	mean	sd	p5	p50	p95
AUM (bln)	6.70	33.73	0.06	0.76	24.07
Funding ratio	110.80	15.91	92.46	108.70	134.40
Required funding ratio	116.80	4.88	108.80	116.60	125.00
Net contributions (% AUM)	0.21	0.76	-0.73	0.08	1.61
Allocation fixed income	55.25	19.03	19.82	56.23	88.03
Allocation cash	2.42	4.19	-0.41	1.28	9.42
Allocation equity	33.42	11.98	16.27	32.14	53.96
Duration liabilities	19.24	3.82	13.60	18.90	25.80
Duration portfolio	11.73	5.57	3.50	11.04	21.89
Duration assets	4.29	2.40	0.98	3.91	9.18
Duration swaps	8.59	5.72	0.70	7.50	19.30

Panel B: Monthly Bond Holdings Data

	mean	sd	p5	p50	p95
% Euro Area	70.04	18.52	35.91	70.77	100.00
% Corporate bonds	34.07	20.78	0.00	34.06	69.09
% Government bonds	65.93	20.78	30.91	65.94	100.00
% in Germany	31.67	18.55	5.51	29.34	66.66
% in Netherlands	20.86	18.97	0.00	18.43	58.62

Panel C: Monthly Market Data

	mean	sd	p5	p50	p95
German 10-year yield	0.53	0.79	-0.58	0.41	1.86
Euribor 20-year swap rate	1.37	0.81	0.05	1.40	2.62
Return MSCI Index	8.23	49.77	-92.56	15.05	81.56
Return IG Bond Index	1.40	17.55	-30.49	4.10	24.81

Table 2: **Funding constraints and swap usage**: We regress portfolio, swap, and asset duration on the lagged funding ratio. Controls include the lagged liability duration, log AUM, net contributions, and the lagged required funding ratio. Fund and time fixed effects are included as indicated. Standard errors are clustered at the fund level and reported in brackets. The quarterly sample period is 2012Q1-2022Q4. Significance: ***99%, **95%, *90%.

	Portfolio Duration		**Swap Duration**		**Asset Duration**	
	(1)	(2)	(3)	(4)	(5)	(6)
Funding ratio ($t-1$)	-3.984***	-6.032**	-3.309**	-6.033**	-0.678	0.044
	[1.457]	[2.883]	[1.614]	[3.087]	[0.616]	[1.186]
Liability duration ($t-1$)	0.467***	0.368**	0.467***	0.465**	0.006	-0.092
	[0.146]	[0.179]	[0.153]	[0.192]	[0.073]	[0.111]
Log AUM ($t-1$)	5.223***	1.94	5.298***	1.933	-0.123	-0.02
	[1.148]	[1.442]	[1.195]	[1.509]	[0.471]	[0.596]
Net contributions ($t-1$)	-0.132	0.295	-0.261	0.158	0.142	0.152
	[0.392]	[0.367]	[0.410]	[0.375]	[0.159]	[0.163]
Required funding ratio ($t-1$)	-25.133***	-36.208***	-17.541***	-31.369***	-7.769***	-5.054**
	[4.852]	[6.876]	[5.259]	[7.674]	[1.834]	[2.495]
Time FE	No	Yes	No	Yes	No	Yes
Fund FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	6684	6684	6684	6684	6684	6684
R^2	0.68	0.72	0.70	0.74	0.63	0.64

Table 3: **Bond holdings and maximum 10-day changes in swap rates**: This table shows the results of regressing monthly net purchases of bonds relative to AUM on the maximum 10-day change in the 20-year swap rate within the month (Column 1), the corresponding swap rate change interacted with the swap duration (Column 2), and the swap rate change interacted with the swap duration and with the bond duration (Columns 3-4). We also run similar regressions using an indicator variable whether the maximum swap rate change is in the 90th percentile of the distribution ($\mathbb{1}\{\text{High}\}$; Columns 5-8). Controls include current and lagged changes in hypothetical bond allocations as specified in Equation (4), funding ratio, net contributions, required funding ratio, and liability duration. Fund and time fixed effects are included as indicated. The monthly sample period is 2012M1-2022M12. Standard errors are clustered at the fund and time level and reported in brackets. Significance: ***99%, **95%, *90%.

	Net Buys/AUM							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δr^S	-0.783***	0.427	1.628*					
	[0.283]	[0.497]	[0.946]					
$Dur^S\ (t-1) \times \Delta r^S$		-0.158**	-0.176**	-0.166**				
		[0.068]	[0.068]	[0.071]				
$Dur^B\ (t-1) \times \Delta r^S$			-0.257	-0.242				
			[0.188]	[0.198]				
$\mathbb{1}\{\text{High}\}$					-0.278**	0.182	0.441	
					[0.112]	[0.229]	[0.355]	
$Dur^S\ (t-1) \times \mathbb{1}\{\text{High}\}$						-0.057**	-0.061**	-0.062**
						[0.026]	[0.026]	[0.027]
$Dur^B\ (t-1) \times \mathbb{1}\{\text{High}\}$							-0.055	-0.058
							[0.054]	[0.063]
$Dur^S\ (t-1)$		0.024	0.032*	0.033**		0.006	0.011	0.015
		[0.018]	[0.017]	[0.016]		[0.015]	[0.014]	[0.013]
$Dur^B\ (t-1)$			0.113***	0.111***			0.083***	0.081***
			[0.041]	[0.037]			[0.026]	[0.027]
Relative bond return (t)	1.174	1.181	0.887	-7.668	2.082	1.919	1.697	-7.365
	[3.075]	[2.954]	[2.941]	[11.597]	[3.382]	[3.276]	[3.225]	[11.308]
Relative bond return ($t-1$)	-8.355*	-8.622*	-8.719*	-21.788*	-6.67	-7.103	-7.272	-21.578*
	[4.794]	[4.646]	[4.635]	[12.176]	[4.973]	[4.822]	[4.798]	[12.469]
Relative bond return ($t-2$)	-8.665**	-9.138***	-9.231***	-24.823**	-8.091**	-8.538**	-8.599**	-24.209**
	[3.353]	[3.169]	[3.173]	[10.776]	[3.521]	[3.343]	[3.334]	[10.649]
Funding ratio ($t-1$)	0.004	0.001	0.001	-0.004	0.004	0.001	0.002	-0.005
	[0.002]	[0.003]	[0.003]	[0.010]	[0.003]	[0.004]	[0.004]	[0.010]
Net contributions ($t-1$)	0.348**	0.128	0.177	-0.136	0.348**	0.14	0.186	-0.13
	[0.142]	[0.251]	[0.242]	[0.247]	[0.142]	[0.251]	[0.242]	[0.247]
Required funding ratio ($t-1$)	0.002	0.014	0.019	0.03	0.001	0.012	0.018	0.03
	[0.007]	[0.015]	[0.016]	[0.018]	[0.007]	[0.015]	[0.016]	[0.019]
Liability duration ($t-1$)	-0.026	-0.112***	-0.122***	0.022	-0.025	-0.110***	-0.119***	0.026
	[0.018]	[0.031]	[0.030]	[0.049]	[0.018]	[0.031]	[0.031]	[0.046]
Fund FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Time FE	No	No	No	Yes	No	No	No	Yes
Obs.	4560	4560	4560	4560	4560	4560	4560	4560
R^2	0.01	0.02	0.03	0.06	0.01	0.02	0.02	0.06

Table 4: **Margin call risk and selling of AAA medium-term bonds**: In Columns 1-3, we perform regressions of the percentage change in monthly individual-level nominal bond holdings on the lagged swap duration interacted with a dummy that indicates whether the bond is an AAA-rated government bond, denominated in euros, and with a remaining time to maturity above one during periods of interest rate surges: 2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12. In Columns 4-6, we also interact with a dummy that indicates whether the bond has a remaining time-to-maturity that is below 7 years. Time, security, and fund-time fixed effects are included as indicated. Standard errors are clustered at the security level and reported in brackets. Significance: ***99%, **95%, *90%.

	$\%Hold$					
	(1)	(2)	(3)	(4)	(5)	(6)
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\}$	-0.086***	-0.077***	-0.061**	-0.007	-0.001	0.002
	[0.028]	[0.028]	[0.030]	[0.036]	[0.036]	[0.032]
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\} \times \mathbb{1}\{T < 7\}$				-0.196***	-0.190***	-0.147***
				[0.053]	[0.054]	[0.046]
$Dur^S(t-1) \times \mathbb{1}\{T < 7\}$				0.01	0.006	0.031***
				[0.008]	[0.008]	[0.012]
$\mathbb{1}\{\text{AAA Bond}\} \times \mathbb{1}\{T < 7\}$				1.426**	1.318**	
				[0.599]	[0.602]	
$Dur^S(t-1)$	0.011***	0.003		0.006	0.00	
	[0.004]	[0.004]		[0.006]	[0.006]	
$\mathbb{1}\{\text{AAA Bond}\}$	0.607*	0.557*		0.051	0.05	
	[0.321]	[0.319]		[0.402]	[0.398]	
$\mathbb{1}\{T < 7\}$				-0.084	-0.011	
				[0.114]	[0.114]	
Time FE	No	Yes	No	No	Yes	No
Security FE	No	No	Yes	No	No	Yes
Fund-Time FE	No	No	Yes	No	No	Yes
Obs.	420118	420118	415830	420118	420118	415830
R^2	0.00	0.02	0.15	0.00	0.02	0.15

Table 5: **Price impact of margin call risk**: The dependent variables are 10-day bond returns during periods of swap rate surges. The main independent variables are the lagged measure of margin call risk (MC ($t-1$)) as defined in Equation (6), using lagged swap durations as proxy for margin call risk in Columns (1) and (2) and realized margin calls in Columns (3) and (4), and the counterfactual proxy for margin call risk (CF ($t-1$)) as defined in Equation (8) in Columns (5) and (6). Controls include time-to-maturity (TTM), time-to-maturity squared (TTM^2), time since issuance (Age), coupon rates (Coupon), log total amount outstanding (Log(Outst)), an indicator whether the bond is inflation-linked ($\mathbb{1}\{\text{Inflation-Linked}\}$), and an indicator whether the bond is issued by the Netherlands ($\mathbb{1}\{\text{Dutch}\}$). In Columns (2), (4), and (6) we also control for year-to-maturity fixed effects. Periods with swap rate surges are 2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12. As realized margin calls are only available from 2018 onward, Columns (3) and (4) do not include the first two surge episodes. Standard errors are clustered at the bond-level and reported in brackets. Significance: ***99%, **95%, *90%.

	Margin Call Proxy		**Margin Call Realized**		**Counterfactual**	
	(1)	(2)	(3)	(4)	(5)	(6)
MC ($t-1$)	-0.011**	-0.012***	-0.046***	-0.048***		
	[0.004]	[0.004]	[0.008]	[0.008]		
CF ($t-1$)					-0.001	-0.003
					[0.004]	[0.004]
TTM	-0.139***		-0.130***		-0.152***	
	[0.047]		[0.046]		[0.051]	
TTM^2	-0.019**		-0.020**		-0.017*	
	[0.009]		[0.009]		[0.010]	
Age	-0.015***		-0.009**	-0.009**	-0.017***	-0.017***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.005]	[0.005]
Coupon	0.050***	0.045***	0.023	0.019	0.061***	0.058***
	[0.017]	[0.017]	[0.015]	[0.015]	[0.019]	[0.018]
Log(Outst)	-0.034	-0.038	-0.027	-0.033	-0.042	-0.049
	[0.029]	[0.029]	[0.028]	[0.029]	[0.030]	[0.030]
$\mathbb{1}\{\text{Inflation-Linked}\}$	-0.005	-0.001	-0.012	-0.007	0.002	0.003
	[0.053]	[0.054]	[0.052]	[0.053]	[0.053]	[0.055]
$\mathbb{1}\{\text{Dutch}\}$	-0.288	-0.281	-0.338*	-0.329*	-0.238	-0.229
	[0.186]	[0.186]	[0.185]	[0.184]	[0.187]	[0.187]
Year-to-maturity FE	No	Yes	No	Yes	No	Yes
Obs.	510	510	390	390	510	510
R^2	0.53	0.53	0.54	0.54	0.53	0.53

Table 6: **GIV regressions**: This table shows the estimates of the aggregate multiplier M, which indicates how much aggregate yields move when 1% of the bond market is sold, using the GIV approach. The dependent variable is the change in the 3-year safe Euro bond yield. Z is defined as the weighted sum of residual changes in holdings, i.e., the GIV. GDP growth and changes in (CPI) inflation are the quarterly GDP growth and inflation changes, split equally across calendar months. The change in fiscal capacity is the annual change in net amount lent versus borrowed, relative to GDP, taken with a one year lag. PC1, PC2, and PC3 are the first three principal components of the residuals in Equation (9). The data are monthly from February 2012 to December 2022. Newey-West standard errors with optimal lags are reported in brackets. Significance: ***99%, **95%, *90%.

	Δy_t^3				
	(1)	(2)	(3)	(4)	(5)
Z	-0.127**	-0.134**	-0.140**	-0.147**	-0.142**
	[0.061]	[0.060]	[0.061]	[0.063]	[0.064]
GDP growth		0.003	0.003	0.003	0.003
		[0.011]	[0.011]	[0.011]	[0.011]
Fiscal (% change)		-0.001	-0.001	-0.001	-0.001
		[0.012]	[0.011]	[0.011]	[0.011]
Inflation (% change)		0.034**	0.035**	0.035**	0.035**
		[0.016]	[0.015]	[0.014]	[0.014]
PC1			0.003	-0.006	-0.006
			[0.011]	[0.004]	[0.004]
PC2			-0.001	0.005	0.005
			[0.011]	[0.006]	[0.006]
PC3					-0.003
					[0.006]
Obs.	131	131	131	131	131
R^2	0.03	0.05	0.06	0.06	0.07

Appendix

A Numerical Example Pension Funds and Swap Usage

We consider a pension fund with assets worth \$120 and liabilities worth \$100. To keep the example simple, we assume that the fund can only invest in a government bond and a stock market index. The stock market index has a duration of zero while the government bond has the same duration as the pension liabilities. We set this duration equal to 20 years. Panel A of Table A4 illustrates the impact of a 1% drop in interest rates on the funding status of this pension fund. As shown in Columns (1) and (2), the decrease in interest rates increases the present value of pension liabilities by \$20 while the market value of bond holdings increase by \$12. Hence, drops in interest rates lower the funding status of the pension fund.

[Insert Table A4 near here]

Expanding on this example, we next assume that the pension fund can use interest rate swaps to hedge this risk. Columns (3) and (4) of Panel A illustrate the impact of a 1% drop in interest rates if the pension fund engages in a fixed receiver position with \$40 notional. As before, the present value of the pension liabilities increases by \$20 and the value of the government bond increases by \$12. In addition, the present value of the swap position increases by \$8 such that the total increase in pension assets is \$20. Therefore, using interest rate swaps allows the pension fund to retain its strategic asset allocation and simultaneously offset the effect of any drops in interest rates.

To further motivate Hypothesis 1, we next examine how the notional amount required for hedging the interest rate risk changes if the pension fund has a worse funding status. To that end, Panel B of Table A4 shows a modified version of the example, now assuming that the pension fund has \$100 of assets instead of \$120. As illustrated in Columns (1) and (2) of Panel B, if the pension fund does not use interest rate swaps, a 1% drop in interest rates leads to a funding gap of \$10. Columns (3) and (4) show that, if the pension fund uses interest rate swaps with notional amount \$50, the drop in interest rates has no effect on the difference between assets and liabilities. Comparing the required notional amount of swaps to the example from Panel A, we can see that the fund with worse funding status needs to use more interest rate swaps if it wants to keep its asset allocation unchanged while, at the same time, hedging the interest rate risk arising from its liabilities.

B Additional Figures and Tables

Figure A1: **Cash flow distribution**

This graph shows the cash flow distribution of pension funds' liabilities in billion EUR on 2018Q4. We aggregate the cash flows for the 42 pension funds in our holdings data sample.

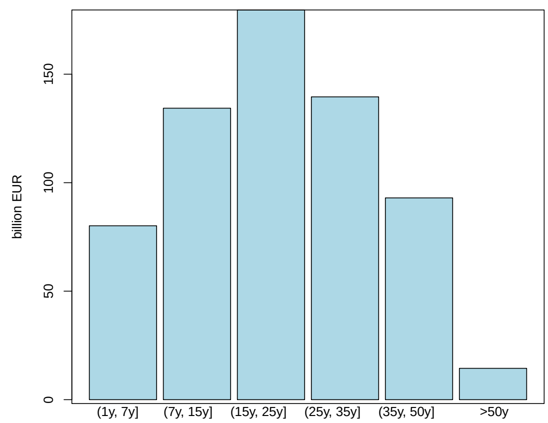


Figure A2: **Usage of interest rate swaps versus other derivatives**

This figure shows the mark-to-market value of interest rate swaps and other derivatives held by Dutch pension funds. These fluctuations show that interest rate swaps are by far the most important derivatives used by Dutch pension funds. Source: DNB public statistics.

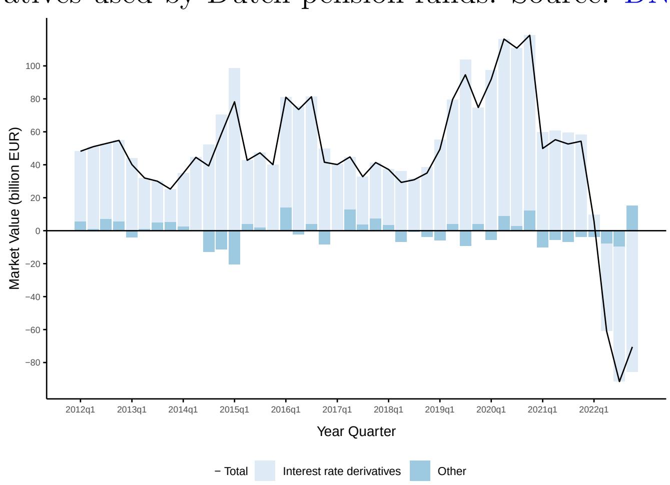


Figure A3: **Price reversals**

This figure plots the cumulative returns of bonds highly exposed to margin call risk versus bonds that have low exposure from March 2, 2020 to May 29, 2020. We define high (low) margin call risk exposure as bonds that are in the 80th (20th) percentile of the margin call measure distribution defined in Equation (6). We include Dutch and German government bonds with remaining time to maturities below seven years. The vertical lines indicate the start and end date of the 10-day surge period. We orthogonalize the component of returns driven by bond characteristics: time-to-maturity, age, coupon, outstanding amount, indicator for inflation-linked bonds, and indicator for issuer (Netherlands or Germany). The weekly moving average returns are averages taken over the past five business days.

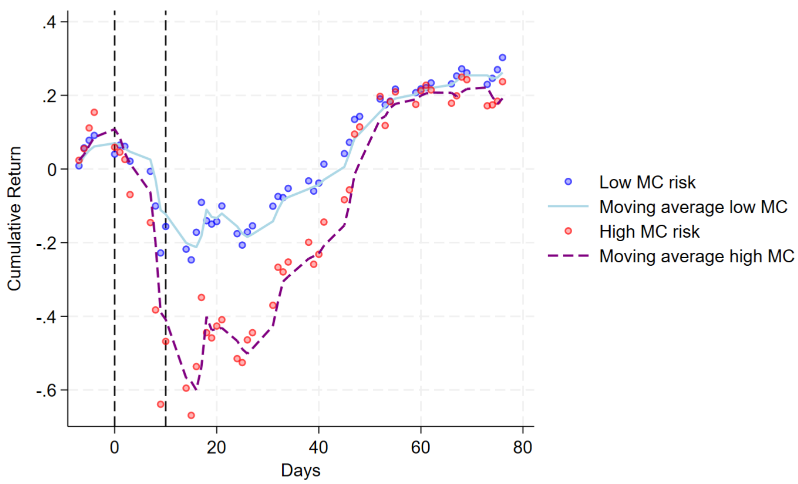


Table A1: **Swap rate surges during the sample period**: This table gives an overview of the months in which 10-day changes in the 20-year swap rate exceed 40 basis points. In addition, it shows the monthly returns of the MSCI Europe stock index and the European Investment Grade bond index in each of the months.

	Changes in Swap Rates		Stock and Bond returns	
Month	10-day Change (%)	Monthly Change (%)	Ret^{MSCI}(%)	Ret^{IG}(%)
May 2015	0.55	0.28	0.5	-0.5
Jun 2015	0.44	0.40	-2.5	-1.9
Mar 2020	0.45	0.11	-13.5	-3.5
Apr 2022	0.42	0.54	-8.4	-3.2
Jun 2022	0.59	0.32	-8.8	-2.5
Aug 2022	0.55	0.62	-4.3	-5.7
Sep 2022	0.50	0.51	-9.5	-4.5
Dec 2022	0.53	0.47	-4.3	-3.9

Table A2: **Margin call risk and selling of AAA medium-term bonds – realized margin calls**: In Columns 1-3, we perform regressions of the percentage change in monthly individual-level nominal bond holdings on the *realized* margin calls interacted with a dummy that indicates whether the bond is an AAA-rated government bond, denominated in euros, and with a remaining time to maturity above one during periods of interest rate surges: 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12 (realized margin calls are only available as of 2018). In Columns 4-6, we also interact with a dummy that indicates whether the bond has a remaining time-to-maturity that is below 7 years. Time, security, and fund-time fixed effects are included as indicated. Standard errors are clustered at the security level and reported in brackets. Significance: ***99%, **95%, *90%.

	$\%Hold$					
	(1)	(2)	(3)	(4)	(5)	(6)
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\}$	-0.190***	-0.167**	-0.164**	-0.044	-0.037	-0.07
	[0.068]	[0.068]	[0.084]	[0.088]	[0.089]	[0.093]
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\} \times \mathbb{1}\{T < 7\}$				-0.345**	-0.312**	-0.238*
				[0.135]	[0.137]	[0.143]
$Dur^S(t-1) \times \mathbb{1}\{T < 7\}$				0.00	-0.022	0.067*
				[0.025]	[0.025]	[0.034]
$\mathbb{1}\{\text{AAA Bond}\} \times \mathbb{1}\{T < 7\}$				0.88	0.674	
				[0.713]	[0.719]	
$Dur^S(t-1)$	-0.060***	-0.117***		-0.061***	-0.106***	
	[0.012]	[0.012]		[0.019]	[0.019]	
$\mathbb{1}\{\text{AAA Bond}\}$	0.284	0.179		-0.102	-0.108	
	[0.359]	[0.361]		[0.438]	[0.438]	
$\mathbb{1}\{T < 7\}$				0.044	0.205	
				[0.143]	[0.144]	
Time FE	No	Yes	No	No	Yes	No
Security FE	No	No	Yes	No	No	Yes
Fund-Time FE	No	No	Yes	No	No	Yes
Obs.	301604	301604	296684	301604	301604	296684
R^2	0.00	0.02	0.15	0.00	0.02	0.15

Table A3: **Margin call risk and selling of illiquid bonds**: We perform regressions of the percentage change in monthly individual-level nominal bond holdings on the lagged swap duration interacted with a dummy that indicates whether the bond is an AAA-rated government bond, denominated in euros, and with a remaining time to maturity above one or an illiquid bond during periods of interest rate surges: 2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12. Illiquid bonds are defined as those bonds with a bid-ask spread in the 80th percentile of the distribution. Time, security, and fund-time fixed effects are included as indicated. Standard errors are clustered at the security level and reported in brackets. Significance: ***99%, **95%, *90%.

	$\Delta\%Hold$			
	(1)	(2)	(3)	(4)
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\}$	-0.095***	-0.085***	-0.072**	-0.083***
	[0.028]	[0.028]	[0.031]	[0.031]
$Dur^S(t-1) \times \mathbb{1}\{\text{Illiquid Bond}\}$	0.003	-0.005	0.012	0.007
	[0.016]	[0.016]	[0.017]	[0.017]
$Dur^S(t-1)$	0.000	-0.002	-0.018***	
	[0.005]	[0.005]	[0.005]	
$\mathbb{1}\{\text{AAA Bond}\}$	0.599*	0.544*		
	[0.316]	[0.314]		
$\mathbb{1}\{\text{Illiquid Bond}\}$	0.272	0.335*		
	[0.200]	[0.199]		
Time FE	No	Yes	Yes	No
Security FE	No	No	Yes	Yes
Fund-Time FE	No	No	No	Yes
Obs.	304543	304543	304543	302822
R^2	0.00	0.02	0.02	0.12

Table A4: **Example duration hedging with interest rate swaps**: This table illustrates how interest rate swaps can be used to hedge the duration risk of a pension fund and how the funding status affects the usage of interest rate swaps. The following five assumptions simplify the example: (i) The pension fund can invest in a broad stock index, a government bond, and receive the fixed rate in an interest rate swap; (ii) The pension fund uses a fixed strategic assets allocation of 50% bonds and 50% equities; (iii) stocks have a duration of zero; (iv) the government bond has the same duration as the pension liabilities, which we set to 20 years; (v) the interest rate swap has the same duration as the liabilities and the initial margin requirement is zero. There are two points in time: The initial investment and the time after a 1% drop in interest rates.

	Without swap usage		With interest rate swaps	
	(1) Initial position	(2) 1% rate drop	(3) Initial position	(4) 1% rate drop
Panel A: Pension fund with 120% funded ratio				
Assets:	$120	$132	$120	$140
Stocks	$60	$60	$60	$60
Bonds	$60	$72	$60	$72
Swap notional: $40	–	–	$0	$8
Liabilities				
PV(L)	$100	$120	$100	$120
Assets - Liabilities	$20	$12	$20	$20
Panel B: Pension fund with 100% funded ratio				
Assets:	$100	$110	$100	$120
Stocks	$50	$50	$50	$50
Bonds	$50	$60	$60	$60
Swaps notional: $50	–	–	$0	$10
Liabilities				
PV(L)	$100	$120	$100	$120
Assets - Liabilities	$0	$-10	$0	$0

Internet Appendix

Not for publication

IA.1 Additional Analysis

In this Internet Appendix, we present additional descriptive statistics and empirical results that were omitted in the body of the paper.

Figure IA.1 shows a time-series of the daily level and changes of the 20-year swap rate.

[**Insert Figure IA.1 near here**]

Figure IA.2 plots a time-series of the cross-sectional average funding ratio and the cross-sectional average counterfactual funding ratio, whereby the latter assumes a zero swap exposure.

[**Insert Figure IA.2 near here**]

Figure IA.3 illustrates the correlation between our proxy for margin call risk and the factual margin calls reported by pension funds.

[**Insert Figure IA.3 near here**]

Figure IA.4 illustrates the strong negative correlation between the funding ratio and our proxy for margin call risk over time.

[**Insert Figure IA.4 near here**]

Figure IA.5 plots the cumulative distribution of aggregate net buys of MMFs against the cumulative distribution of realized margin calls.

[Insert Figure IA.5 near here]

Figure IA.6 shows a binned scatter plot of pension funds' swap durations against their asset durations.

[Insert Figure IA.6 near here]

Figure IA.7 shows a binned scatter plot of pension funds' medium-term bond holdings against their funding ratios.

[Insert Figure IA.7 near here]

Figure IA.8 shows the bid-ask spreads for German and Dutch government debt by maturity buckets.

[Insert Figure IA.8 near here]

Figure IA.9 shows the inputs into our GIV methodology described in Section 5.2.

[Insert Figure IA.9 near here]

Robustness to Alternative Specification

In the paper, we use the *level* of the lagged funding ratio to explain the swap durations. An alternative specification would be to use changes in the funding ratio and swap durations. However, using contemporaneous changes in both funding ratios and swap durations is problematic because of endogeneity concerns. For instance, if a pension fund decides to lower (increase) its swap duration, it simultaneously affects their funding ratio negatively when the realized interest rate is lower (higher).

To overcome this issue we use the plans allocation to stocks multiplied with the return on the MSCI World Index as an instrument for changes in the funding ratio. More specifically, we run regressions of the following form:

$$\Delta Dur_{i,t} = \beta \widehat{\Delta FR}_{i,t} + \Delta C_{i,t} + \varepsilon_{i,t}, \tag{IA.1}$$

where $\widehat{\Delta FR}_{i,t}$ is the projected change in funding ratio. Because the instruments are highly correlated across funds, adding time fixed effects would absorb most variation. Hence, instead of controlling for time fixed effects, we control for changes in 10-year German government bond yields.[33]

Table IA.1 shows the results of this analysis. As before, we find a negative link between funding ratio and portfolio duration with most of the portfolio adjustments coming from changes in the swap duration.

[Insert Table IA.1 near here]

Table IA.2 shows that our results are qualitatively similar when using the lagged funding gap instead of the funding ratio. Notice that the coefficient on the lagged funding gap has the opposite sign: a higher (lower) funding gap implies that the pension funds is worse (better) funded.

[Insert Table IA.2 near here]

Table IA.3 presents summary statistics for the pension funds that are covered in the holdings data. Apart from pension fund size, the characteristics of the pension funds covered in the holdings data are similar to those in the full sample of pension funds (Table 1).

[33] We do not control for changes in net contributions, because they are reported annually and hence the changes are zero for most quarters.

[Insert Table IA.3 near here]

Table IA.4 shows that we obtain similar conclusions on the net selling of fixed income securities when we use the monthly change in the 20-year swap rate instead of the maximum ten-day change in the 20-year swap rate.

[Insert Table IA.4 near here]

Table IA.5 summarizes the results on the net selling of fixed income securities when we instead instrument maximum swap rate changes with the effect of MPS on the 20-year Euro OIS rate.

[Insert Table IA.5 near here]

Table IA.6 summarizes the results on the liquid bond sales when we condition our event months on those in which the effect of MPS on the 20-year Euro OIS rate was positive.

[Insert Table IA.6 near here]

Table IA.7 shows the average credit ratings of different Euro-area sovereign bonds during our sample period.

[Insert Table IA.7 near here]

IA.2 Additional Details on Pension Regulation

In this section, we shed more light on the determination of the required funding ratio.

The required funding ratio is comparable to the VaR in bank regulation. The idea behind the ratio is to ensure that the probability of the funding ratio dropping below 100% within the next year is below 2.5%. The formula to obtain the required funding ratio is:

$$S = 1 + \sqrt{\sum_{i,j} \rho_{i,j} S_i S_j},$$

where S_i is the VaR for risk factor i as a fraction of the liability value. There are various risk factors, of which the most important are interest rate risk and equity risk, followed by credit and currency risk. The regulator prescribes the shocks for each of the risk factors that pension funds must use to calculate the required funding ratio.

Consider the following example of a pension fund that has liabilities with a duration equal to 20 years. Assume that the fund invests 50% of its assets in stocks and 50% in bonds with a duration of 10 years. In addition, its current funding ratio is equal to 100% and the volatility of the stock return equals 20%. The volatility of interest rate changes is 0.8% with a correlation of 0.4 to stock returns. Using the 97.5th percentile of the standard normal distribution, which equals 1.96, the interest and stock risk factors are $S_r = 1.96 \times (20 - 50\% \times 10) \times 0.8\% = 23.5\%$ and $S_s = 1.96 \times 50\% \times 20\% = 19.6\%$, respectively. The required funding ratio in this example is therefore given as

$$S = 1 + \sqrt{S_r^2 + S_s^2 + 2\rho S_r S_s} = 136.1\%.$$

This risk-based capital requirement distinguishes Dutch pension regulation from the US, where regulators focus on the funding ratio but do not require risk-based capital requirements (Boon, Brière, and Rigot, 2018).

IA.3 Deriving Bond and Swap Duration

For the full sample period from 2012Q1 to 2022Q4, the duration of the fixed income portfolio is directly observable from regulatory filings. As of 2015Q1, pension funds also directly report the duration of their swap portfolios. However, between 2012Q1 and 2015Q1 we have to infer the swap durations in a different way. As of 2012Q1, pension funds report the market value of their swap portfolios. Moreover, they report the values of these positions after a parallel shock in interest rates of +1 percent (-1 percent) and +0.5 percent (-0.5 percent). These reporting requirements allow us to compute the dollar durations of the swap positions.

Formally, we approximate the dollar duration of the swap position as follows:

$$D_{p,t}^{\$} \approx -\frac{dV_t}{dr} = \frac{V_t^{-dr} - V_t^{+dr}}{2|dr|} \tag{IA.2}$$

where V_t^{-dr} (V_t^{+dr}) is the value of the swap portfolio after a negative (positive) change in interest rates; $D_p^{\$}$ is the dollar duration of the portfolio; and dr is the change in interest rates.

In addition, to validate our methodology, we conduct a comparative analysis between the implied dollar durations and the swap durations reported by pension funds starting from 2015Q1, observing a strong correlation of 0.86 between these two measures.

IA.4 An Illustrative Model

We now use a simple static model to illustrate the link between duration hedging and funding ratios. To that end, we consider the sponsor of a pension plan with assets A and flow-rate of liabilities L and make three simplifying assumptions. First, we ignore any contributions by the sponsor and assume a constant flow-rate L over an infinite time horizon. Second, there exists a consolbond P with drift μ_B and variance σ_B such that the present value of the liabilities is given as $PV(L) = LP$.[34] Third, the fund has three investment opportunities: a risk-free bank account with stochastic interest rate r_t, the consolbond P, and a stock portfolio S with drift μ and variance σ, which is uncorrelated with the dynamics of the consolbond. The sponsor then maximizes the plan's funding status $F = A - LP$.[35] If we assume that the pension fund is banned from using direct leverage, the following proposition holds.

Proposition 1. *The pension fund has a demand for swaps if* $F \leq \frac{\mu-\mu_B}{\gamma\sigma^2}$. *In this situation, the demand is given as:*

$$s = \frac{\mu - \mu_B}{\gamma(\sigma^2 + \sigma_B^2)} - \frac{\sigma^2}{\sigma^2 + \sigma_B^2}(A - LP). \tag{IA.3}$$

Proposition 1 implies that pension funds use more swaps when they face tighter constraints in the form of lower funding ratios.

To prove Proposition 1, we first note that the fund's optimization problem is to choose its allocation of a dollar amount a to stocks and b to bonds. The optimization problem is then given as:

$$\max_{a,b} \{\mathbb{E}[F] - \gamma Var(F)\}$$
$$\text{subject to: } a + b \leq A, a \geq 0, b \geq 0. \tag{IA.4}$$

[34] We assume stochastic interest rates r_t, but for our applications the exact process of the rates are irrelevant as long as we can obtain μ_B and σ_B.

[35] This assumption is motivated by the institutional setting—pension funds can pay higher indexation if the funding status is closer to 140% and most funds have a funding status below that threshold.

Next, we show that the pension fund is constrained in its asset allocation if:

$$F \leq \frac{\mu - r}{\gamma\sigma^2} + \frac{\mu_B - r}{\gamma\sigma_B^2}. \tag{IA.5}$$

In that case, using interest rate swaps allows the fund to hedge the duration of its liabilities more efficiently. Specifically, we assume that the swap has a zero present value and fixed and variable payments of μ_B and r_t, respectively. If the pension fund is allowed to use swaps to optimize its duration hedging, we can prove the following proposition. To start the proof, note that the Lagrange function is given as:

$$\mathcal{L}(a, b, \lambda) = (\mu - r)a + (\mu_B - r)b - \frac{\gamma\sigma^2}{2}a^2 - \frac{\gamma\sigma_B^2}{2}(b - LP)^2 - \lambda(a + b - A),$$

where μ_B and σ_B are the mean and variance of the bond. Taking first-order conditions gives:

$$\frac{\partial\mathcal{L}}{\partial a} : (\mu - r) - \gamma\sigma^2 a - \lambda \overset{!}{=} 0$$
$$\frac{\partial\mathcal{L}}{\partial b} : (\mu_B - r) - \gamma\sigma_B^2(b - LP) - \lambda \overset{!}{=} 0$$
$$\frac{\partial\mathcal{L}}{\partial \lambda} : a + b - A \leq 0$$

If the last equation holds with equality, the fund is constrained and we obtain $b = A - a$ and $\lambda > 0$. If the fund is unconstrained, $\lambda = 0$ and we obtain:

$$a = \frac{\mu - r}{\gamma\sigma^2} \text{ and } b = LP + \frac{\mu_B - r}{\gamma\sigma_B^2}.$$

Note that these unconstrained allocations make intuitive sense: The sponsor hedges the risk arising from LP and, on top of that, chooses mean-variance maximizing allocations to both bonds and stocks. With binding constraint we obtain:

$$a = \frac{\mu - r - \lambda}{\gamma\sigma^2} \text{ and } b = LP + \frac{\mu_B - r - \lambda}{\gamma\sigma_B^2} \stackrel{!}{=} A - a,$$

which gives:

$$\lambda = \mu_B - r - \gamma\sigma_B^2(A - a - LP).$$

Plugging this into a and b gives:

$$\begin{aligned}
a &= \frac{\mu - \mu_B}{\gamma(\sigma^2 + \sigma_B^2)} + \frac{\sigma_B^2}{\sigma^2 + \sigma_B^2}(A - LP) \\
b &= A - \frac{\sigma_B^2}{\sigma^2 + \sigma_B^2}(A - LP) - \frac{\mu - \mu_B}{\gamma(\sigma^2 + \sigma_B^2)}
\end{aligned}$$

Then we obtain:

$$LP - b = \frac{\mu - \mu_B}{\gamma(\sigma^2 + \sigma_B^2)} - \frac{\sigma^2}{\sigma^2 + \sigma_B^2}\left(A - LP\right).$$

This expression is positive if Equation (IA.5) holds.

Swap Demand

To conclude the proof, we need to show that the utility of using swaps is highest when the fund uses swaps such that $b + s = LP$. To that end, we analyze the target function:

$$f(a, b, s) = (\mu - r)a + (\mu_B - r)(b + s) - \frac{\gamma\sigma^2}{2}a^2 - \frac{\gamma\sigma_B^2}{2}(b + s - LP)^2.$$

Comparing the target function for $s = LP - b$ to $s = 0$ shows:

$$f(a^c, b^c, LP - b^c) - f(a^c, b^c, 0) = \frac{\gamma\sigma_B^2}{2}(b^c - LP)^2 + (\mu_B - r)(LP - b^c) > 0.$$

Hence, the utility is higher if the pension fund uses swaps compared to not using swaps. To complete the proof, we show that f is decreasing on the interval $s \in [0, LP - b]$:

$$\begin{aligned} \frac{\partial}{\partial x} f(a^c, b^c, LP - b^c - x) &= \frac{\partial}{\partial x}\left[(\mu - r)a + (\mu_B - r)(LP - x) - \frac{\gamma\sigma^2}{2}a^2 - \frac{\gamma\sigma_B^2}{2}x^2\right] \\ &= -(\mu_B - r) - \gamma\sigma_B^2 x < 0. \end{aligned}$$

Therefore, the utility of the pension fund is highest for using swaps with notional $s = LP - b$.
■

IA.5 Numerical Example Illustrating Margin Call Risk

To illustrate how swap usage can force pension funds to sell parts of their asset portfolios, we consider a modified version of the example discussed in Appendix A. We compare two pension funds which both have assets and liabilities worth \$100 and construct the example such that both have the same exposure to changes in interest rates. As before, we keep the example simple and assume that the fund can only invest in a government bond and a stock market index. The stock market index has a duration of zero while the government bond has the same duration as the pension liabilities. The first pension fund can also use interest rate swaps to hedge its duration risk while the second fund only uses the bond for hedging. We set the duration of the bond, the liabilities, and the swap equal to 20 years. In addition, we assume that the pension funds both hold the same amount of cash and set this amount to \$2.5.

The first fund holds \$55 in bonds and uses interest rate swaps with a notional amount of \$25. The second fund holds \$80 in bonds. Both funds invest their remaining assets in stocks. We then consider the effect of a 1% interest rate increase on the portfolios of the two pension funds. Table IA.8 illustrate the impact of a 1% increase in interest rates on the funding status and portfolio of the two pension funds. In both cases, the total asset value decreases from \$100 to \$84 while the present value of the liabilities decreases from \$100 to \$80. Hence, the increase in interest rates *improved* the funding status of both funds.

[Insert Table IA.8 near here]

Columns (1) and (2) show that the the first fund must liquidate part of its asset holdings in response to the interest rate increase. Because the present value of the swap dropped to \$-5, the pension fund must post this amount as cash collateral due to variation margin requirements. Because the fund only has cash holdings worth \$2.5, it needs to sell \$2.5 of its \$44 bond holdings. By contrast, the second fund does not need to sell any assets immediately in response to the rate hike. Hence, increasing interest rates expose pension funds with larger swap positions to market liquidity risk.

IA.6 External Validity

We now provide suggestive evidence that our results extend beyond the Dutch pension sector. Our external validity test is based on publicly available data on insurance companies in Europe obtained from EIOPA.[36] EIOPA reports quarterly asset allocations and derivative positions of insurance companies at the country-insurance type level since 2017.

[36]The data are available through EIOPA public statistics.

In our analysis, we focus on the aggregate insurance sector.[37] Similar to pension funds, (life) insurance companies use interest rate derivatives to hedge the long-term nature of their liabilities. EIOPA reports the market value of the long and short derivative positions that include all derivative types. However, the majority of their derivative portfolio (around 69%) consists of interest rate derivatives (EIOPA, 2022). In addition, we focus our analysis on the following countries: Denmark, France, Germany, Ireland, Netherlands, Norway, and Sweden. The reason we exclude the other European countries is because of their limited use of interest rate derivatives (EIOPA, 2022, page 25), whereby the total notional amount in derivatives as a percentage of AUM is below 2%.

We focus on the period from 2021Q4 to 2022Q3, when the 20-year swap rate increased by 2 percentage points. We then compute the total change in the fixed income allocation over this period, which equals the change in the total value of the fixed income portfolio, relative to the AUM at the start of the period. We then compare it to the realized margin call over the same period, which is computed as the difference in the net market value of the derivative portfolio (long minus short position), relative to AUM.

Figure IA.10 summarizes the results. We find a negative relationship between realized margin calls and the bond allocation: countries with larger realized margin calls saw a larger drop in their bond allocations. When we zoom in on liquid bonds, which we define as cash plus government bond portfolios, we uncover a similar relationship: the liquid bond portfolio declined more for those countries that experienced larger margin calls.

[Insert Figure IA.10 near here]

[37]We focus on the aggregate insurance sector, rather than the life insurance sector, because insurers that offer products beyond life are categorized as 'Other'. In addition, categorization can change over time, which in some instances leads to seemingly high volatility in asset allocations if the total number of insurers in a given country is small.

EIOPA only provides asset allocations in market values. Therefore, it is natural that bond allocations decline when the interest rate increases, even in the absence of margin calls. In the cross-section, if countries with large margin calls are also the ones with long durations of their fixed income portfolios, then the negative relationship that we uncover might be mechanical and not the result of margin calls. However, this is unlikely to be the case. For instance, in 2017, the bond duration for Denmark was equal to 5.35, while it was 7.13 for Ireland (EIOPA, 2017). Hence, a rise in interest rates should, all else equal, lower the value of the bond portfolio more for Ireland compared to Denmark. However, in the graph, we observe a larger reduction in the bond portfolio for Denmark than for Ireland. As such, the cross-sectional variation in realized margin calls and the change in bond allocations is more consistent with the margin call channel.

Figure IA.1: **Swap rates**

The blue line shows daily observations of the 20-year swap rate. The black line shows changes in the 20-year swap rate over a 10-business-day period (which aligns with what we describe in the text). The figure shows that 10-day increases like we observed in March 2020 are rare. However, one comparable episode was May/June 2015 and we observe these episodes in 2022.

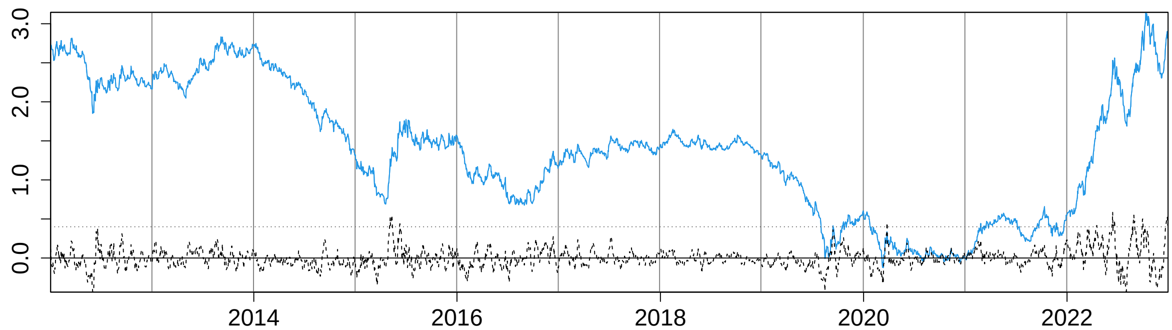


Figure IA.2: **Actual versus counterfactual funding ratios**

This figure plots a time-series average of the actual (blue solid line) and the counterfactual (dashed purple line) funding ratio. The counterfactual funding ratio is computed as the funding ratio assuming that the swap exposure equals zero. The horizontal line indicates the minimum funding requirement and the light grey dotted line reflects the 10-year German yield. The quarterly sample period is 2012Q1-2022Q4.

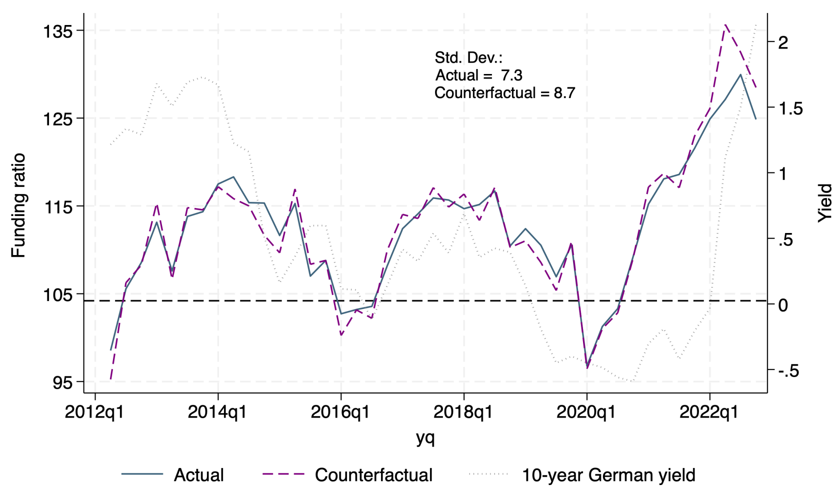


Figure IA.3: **Margin calls: actual versus proxy**

This graph plots the margin call proxy against the reported margin calls for 2020Q1, relative to AUM. The margin call proxy is equal to the swap duration times the change in interest rates. The actual margin calls are reported directly in regulatory reports. Both measures are based on $\Delta r = +1\%$.

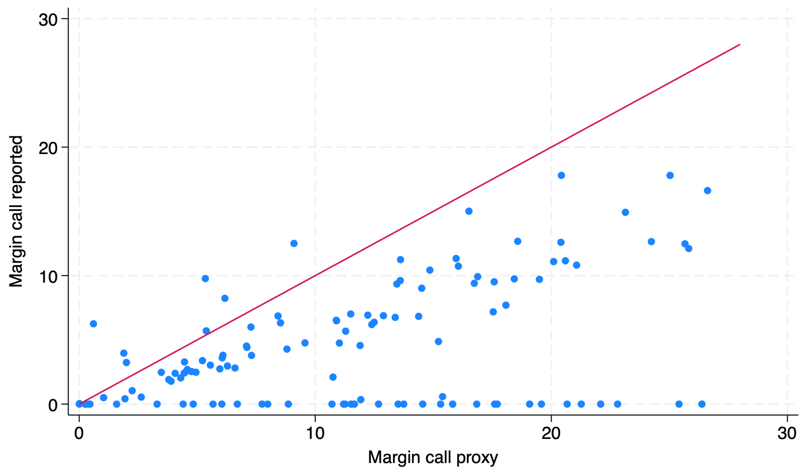


Figure IA.4: **Funding ratios and margin calls**

This figure shows a time-series of the cross-sectional average funding ratio and margin call risk. The margin call risk is computed as the swap duration multiplied by an increase in interest rates of $\Delta r = +1\%$, relative to total AUM. The quarterly sample period is 2012Q1-2022Q4.

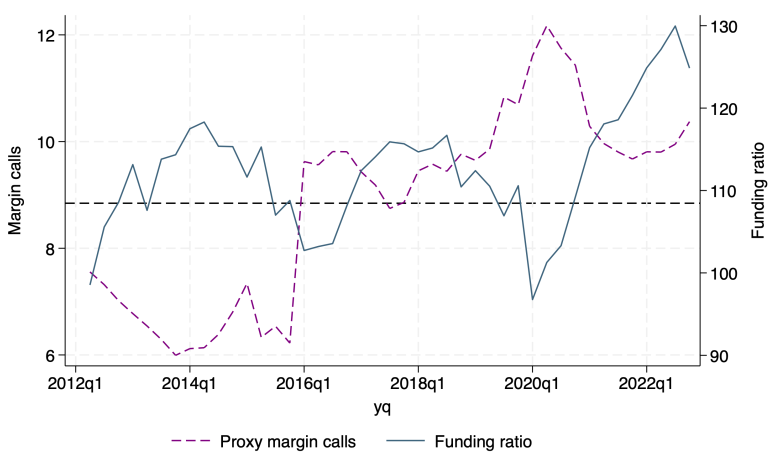


Figure IA.5: **Cumulative money market fund sales**

This figure plots the detrended cumulative distribution of aggregate net buys of money market funds (MMFs) against the detrended cumulative distribution of aggregate realized margin calls. Net buys is defined as the total purchases minus the total sales of MMFs, both at market values and aggregated across pension funds. The realized margin call risk equals the value-weighted lagged swap duration across pension funds, times the maximum realized 10-day change in the 20-year swap rate. The monthly sample period is 2012M1-2022M12.

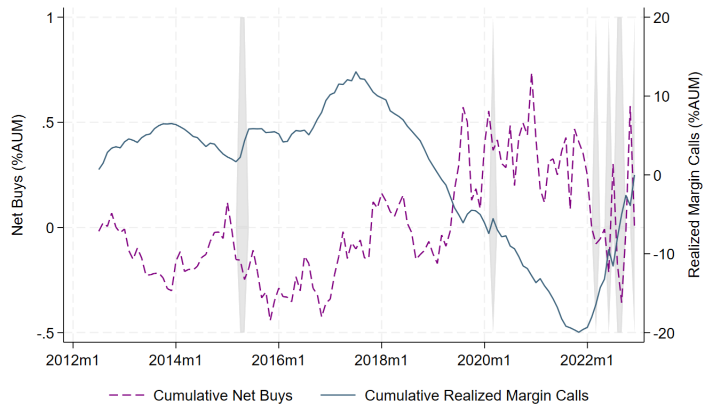


Figure IA.6: **Swap duration versus asset duration**

This graph shows a bin-scatter plot of the swap duration of a given pension fund against its asset duration (i.e., the duration of the fixed income portfolio multiplied by the allocation to fixed income), whereby we split the pension fund-quarter observations in $\sqrt{N} = 89$ groups. The quarterly sample is 2012Q1-2022Q4.

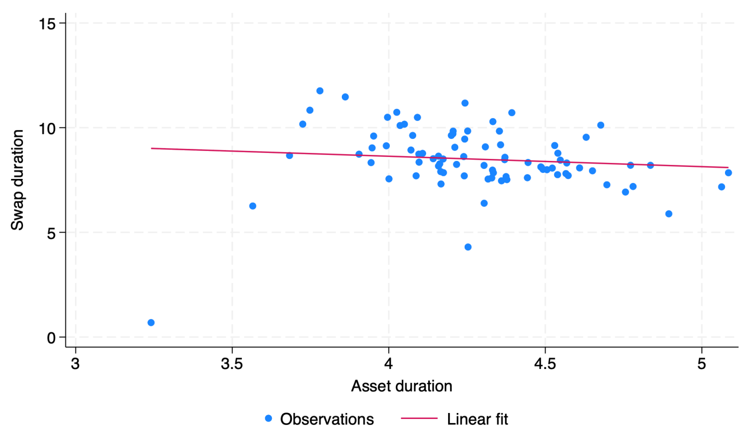


Figure IA.7: **Medium-term bond holdings and the funding ratio**

This graph shows a bin-scatter plot of the lagged funding ratio against the allocation to medium-term bond holdings (as a fraction of total bond holdings). Each dot represents a group of pension fund-quarter observations, whereby we split pension fund-quarter observations in $\sqrt{N} = 41$ groups (we only have medium-term bond allocations for the 42 pension funds in the holdings data sample). The medium-term bond allocation is in percentage points and the quarterly sample period is 2012Q1-2022Q4.

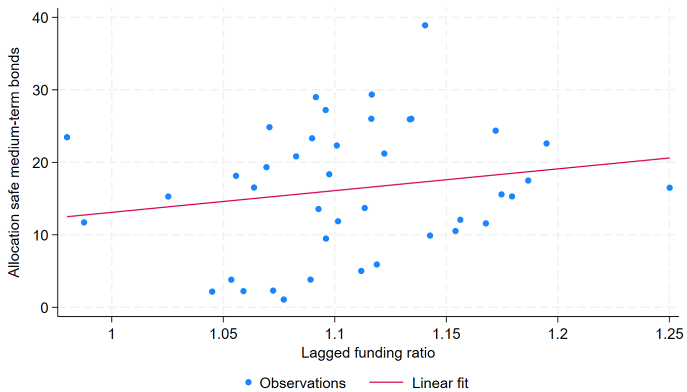


Figure IA.8: **Average bid-ask spreads for German and Dutch debt**

This figure shows the average bid-ask spreads of German and Dutch government bonds separated into three different maturity categories: (i) less than one year; (ii) one to seven years; (iii) more than seven years. The left-hand (right-hand) panel shows the spreads for German (Dutch) debt. The bid-ask spreads are obtained from Eikon.

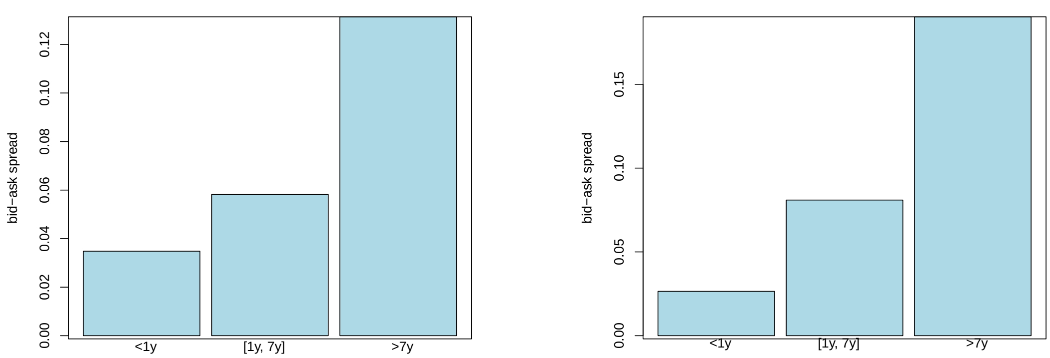
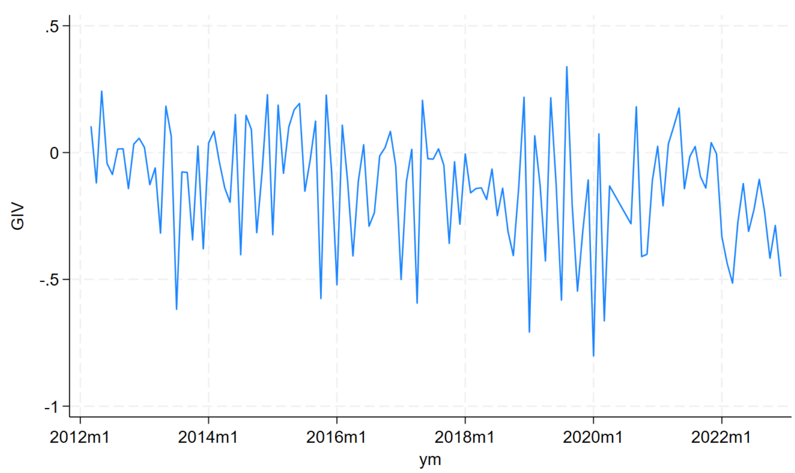


Figure IA.9: **GIV inputs**

Panel (a) shows the total fraction of safe Euro debt held by the investors in our sample over time. Panel (b) shows the GIV that we construct in Section 5.2 over time. The monthly sample period is 2012M1-2022M12.

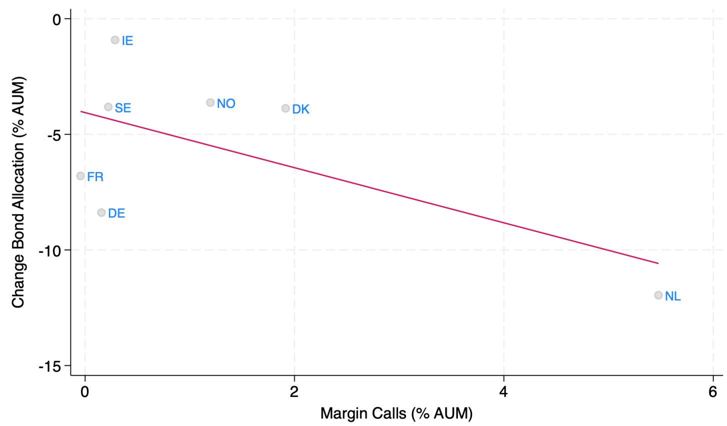
(a) Coverage



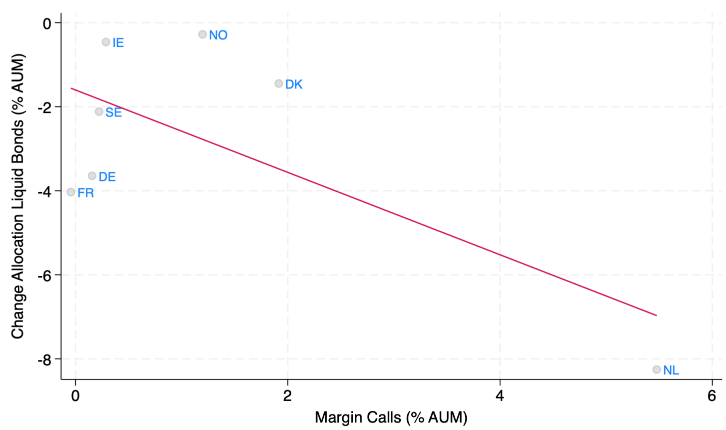
(b) GIV

Figure IA.10: **External Validity**

Panel (a) plots the realized margin calls against the change in the bond allocation for each country over the period from 2021Q4-2022Q3. Panel (b) plots the realized margin calls against the change in the liquid bond allocation for each country. We define the liquid bond allocation as the sum of cash and government bonds. We include the following countries: Denmark (DK), France (FR), Germany (DE), Ireland (IE), Netherlands (NL), Norway (NO), and Sweden (SE). The data are from EIOPA public statistics and we focus on the country-level asset allocations of the aggregate insurance sector.



(a) All bonds



(b) Liquid bonds

Table IA.1: **Funding constraints and swap usage - IV**: We regress *changes* in portfolio, swap, and asset duration on *changes* in the funding ratio, whereby we use the lagged allocation to equities times the return on the MSCI index as an instrument for the change in the funding ratio. Controls include the change in liability duration, AUM, required funding ratio, and the 10-year German yield. Fund fixed effects are included as indicated. Standard errors are clustered at the fund level and reported in brackets. The critical value of the t-stat in Stock, Wright, and Yogo (2002) for rejecting weak instruments equals 4.05. The quarterly sample period is 2012Q1-2022Q4. Significance: ***99%, **95%, *90%.

	Δ Portfolio Duration		**Δ Swap Duration**		**Δ Asset Duration**	
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Funding ratio	-20.206***	-31.403***	-18.602***	-30.246***	-1.723*	-0.785
	[3.206]	[4.196]	[3.346]	[4.228]	[0.923]	[1.028]
Δ Liability duration	-0.079	-0.290**	-0.091	-0.314**	0.004	0.024
	[0.078]	[0.120]	[0.083]	[0.125]	[0.028]	[0.029]
Δ Log AUM	2.123**	3.105**	1.414	2.492	0.718**	0.598*
	[1.078]	[1.411]	[1.208]	[1.512]	[0.306]	[0.305]
Δ Required funding ratio	-6.057***	-10.530***	-7.080***	-11.797***	0.461	0.938
	[1.899]	[2.283]	[1.896]	[2.332]	[0.718]	[0.777]
Δ 10-year German yield	-0.145	0.162	-0.087	0.228	-0.065	-0.088*
	[0.163]	[0.204]	[0.179]	[0.216]	[0.048]	[0.048]
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	6454	6450	6454	6450	6454	6450
First stage:						
Coefficient	0.005	0.005	0.005	0.005	0.005	0.005
t-stat	22.48	20.14	22.48	20.14	22.48	20.14

Table IA.2: **Funding constraints and swap usage - funding gap**: We regress the portfolio, swap, and asset duration on the lagged funding gap. The funding gap is defined as the required funding ratio minus the actual funding ratio. Controls include the lagged liability duration, AUM, net contributions, and required funding ratio. Fund and time fixed effects are included as indicated. Standard errors are clustered at the fund level and reported in brackets. The quarterly sample period is 2012Q1-2022Q4. Significance: ***99%, **95%, *90%.

	Δ Portfolio Duration		**Δ Swap Duration**		**Δ Asset Duration**	
	(1)	(2)	(3)	(4)	(5)	(6)
Funding gap ($t-1$)	4.040***	6.426**	3.355**	6.452**	0.689	-0.07
	[1.467]	[2.897]	[1.634]	[3.229]	[0.629]	[1.256]
Liability duration ($t-1$)	0.465***	0.364**	0.465***	0.461**	0.005	-0.092
	[0.147]	[0.179]	[0.154]	[0.192]	[0.073]	[0.111]
Log AUM ($t-1$)	5.233***	1.921	5.306***	1.913	-0.121	-0.019
	[1.149]	[1.440]	[1.197]	[1.507]	[0.472]	[0.596]
Net contributions ($t-1$)	-0.127	0.303	-0.257	0.165	0.143	0.152
	[0.392]	[0.366]	[0.410]	[0.374]	[0.160]	[0.163]
Required funding ratio ($t-1$)	-29.144***	-42.546***	-20.871***	-37.727***	-8.452***	-4.991*
	[4.978]	[7.325]	[5.390]	[8.218]	[1.919]	[2.920]
Time FE	No	Yes	No	Yes	No	Yes
Fund FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	6684	6684	6684	6684	6684	6684
R^2	0.68	0.72	0.70	0.74	0.63	0.64

Table IA.3: **Summary statistics pension funds in holdings data sample**: This table presents summary statistics for the pension funds that are covered in the holdings data sample. We report the AUM (billions), funding ratio (pp), required funding ratio (pp), net contributions (% AUM), allocation to fixed income (pp), allocation to cash (pp), allocation to equities (pp), and duration of the liabilities, total portfolio, assets, and swaps (years). Cash includes money market funds and deposits with less than one year maturities. The cross-sectional mean, standard deviation, median, 5th percentile, and 95th percentile are reported.

	mean	sd	p5	p50	p95
AUM (bln)	28.32	69.28	2.10	7.94	124.90
Funding ratio	110.80	12.71	92.80	109.20	135.90
Required funding ratio	118.10	4.75	109.20	118.10	125.40
Net contributions (% AUM)	-0.02	0.41	-0.66	-0.04	0.67
Allocation fixed income	54.36	17.26	23.22	53.61	87.54
Allocation cash	1.90	2.99	-1.12	1.18	7.87
Allocation equity	30.88	9.94	13.63	30.49	48.27
Duration liabilities	18.78	2.98	13.70	18.70	23.59
Duration portfolio	11.56	5.00	4.48	10.85	20.82
Duration assets	4.10	1.70	1.53	3.95	7.22
Duration swaps	7.50	4.99	0.70	6.50	16.77

Table IA.4: **Bond holdings and changes in swap rates**: This table shows the results of regressing monthly net purchases of bonds relative to AUM on the monthly change in the 20-year swap rate (Column 1), the corresponding swap rate change interacted with the swap duration (Column 2), and the swap rate change interacted with the swap duration and with the bond duration (Columns 3-4). We also run similar regressions using an indicator variable whether the maximum swap rate change is in the 90th percentile of the distribution ($\mathbb{1}\{\text{High}\}$; Columns 5-8). Controls include current and lagged changes in hypothetical bond allocations as specified in Equation (4), funding ratio, net contributions, required funding ratio, and liability duration. Fund and time fixed effects are included as indicated. The monthly sample period is 2012M1-2022M12. Standard errors are clustered at the fund and time level and reported in brackets. Significance: ***99%, **95%, *90%.

	Net Buys/AUM							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δr^S	-0.518**	0.088	0.286					
	[0.231]	[0.373]	[0.720]					
$Dur^S\ (t-1) \times \Delta r^S$		-0.077*	-0.081*	-0.077*				
		[0.044]	[0.044]	[0.044]				
$Dur^B\ (t-1) \times \Delta r^S$			-0.039	-0.032				
			[0.156]	[0.166]				
$\mathbb{1}\{\text{High}\}$					-0.263**	0.15	0.237	
					[0.105]	[0.200]	[0.321]	
$Dur^S\ (t-1) \times \mathbb{1}\{\text{High}\}$						-0.051**	-0.052**	-0.052**
						[0.025]	[0.025]	[0.026]
$Dur^B\ (t-1) \times \mathbb{1}\{\text{High}\}$							-0.017	-0.008
							[0.047]	[0.052]
$Dur^S\ (t-1)$		0	0.006	0.01		0.005	0.01	0.014
		[0.014]	[0.013]	[0.012]		[0.014]	[0.014]	[0.012]
$Dur^B\ (t-1)$			0.082***	0.078**			0.081***	0.078**
			[0.029]	[0.032]			[0.029]	[0.031]
Relative bond return (t)	-0.612	-0.444	-0.669	-7.122	1.459	1.253	1.008	-6.713
	[2.805]	[2.936]	[2.902]	[11.248]	[2.978]	[3.014]	[2.983]	[11.408]
Relative bond return ($t-1$)	-9.861*	-10.379*	-10.546*	-22.149*	-8.133	-8.710*	-8.873*	-21.807*
	[5.169]	[5.216]	[5.229]	[12.326]	[4.906]	[4.893]	[4.902]	[12.769]
Relative bond return ($t-2$)	-9.597**	-10.158***	-10.163***	-24.682**	-8.894**	-9.458**	-9.489**	-24.169**
	[3.615]	[3.570]	[3.600]	[11.336]	[3.680]	[3.618]	[3.643]	[11.294]
Funding ratio ($t-1$)	0.004	0	0	-0.003	0.004	0	0.001	-0.004
	[0.003]	[0.004]	[0.004]	[0.010]	[0.003]	[0.004]	[0.004]	[0.010]
Net contributions ($t-1$)	0.352***	0.151	0.199	-0.136	0.357***	0.146	0.192	-0.139
	[0.130]	[0.251]	[0.242]	[0.249]	[0.130]	[0.251]	[0.242]	[0.247]
Required funding ratio ($t-1$)	0.001	0.013	0.02	0.032*	0.001	0.011	0.017	0.031*
	[0.007]	[0.015]	[0.016]	[0.018]	[0.007]	[0.015]	[0.016]	[0.018]
Liability duration ($t-1$)	-0.026	-0.108***	-0.117***	0.026	-0.026	-0.110***	-0.119***	0.027
	[0.016]	[0.029]	[0.029]	[0.044]	[0.016]	[0.029]	[0.029]	[0.044]
Fund FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Time FE	No	No	No	Yes	No	No	No	Yes
Obs.	4560	4560	4560	4560	4560	4560	4560	4560
R^2	0.01	0.02	0.02	0.06	0.01	0.02	0.02	0.06

Table IA.5: **Bond holdings and maximum 10-day changes in swap rates - IV**: This table regresses the monthly net purchases of bonds relative to AUM on the maximum 10-day change in the 20-year swap rate within the month (Column 1) and the corresponding swap rate change interacted with the swap duration (Column 3). We also run similar regressions using an indicator variable whether the maximum swap rate change is in the 90th percentile of the distribution ($\mathbb{1}\{\text{High}\}$; Columns 2 and 4). We instrument both the swap rates changes and the indicator variable with the effect of monetary policy surprises on the 20-year Euro OIS rates obtained from Altavilla et al. (2019). Controls include current and lagged changes in hypothetical bond allocations as specified in Equation (4), funding ratio, net contributions, required funding ratio, and liability duration. Fund and time fixed effects are included as indicated. The monthly sample period is 2013M10-2022M12. Standard errors are clustered at the fund level and reported in brackets. Significance: ***99%, **95%, *90%.

	Net Buys/AUM			
	(1)	(2)	(3)	(4)
Δr^S	-2.109**			
	[0.934]			
$\mathbb{1}\{\text{High}\}$		-0.972**		
		[0.431]		
$Dur^S\ (t-1) \times \Delta r^S$			-0.215**	
			[0.105]	
$Dur^S\ (t-1) \times \mathbb{1}\{\text{High}\}$				-0.106**
				[0.051]
$Dur^S\ (t-1)$			0.03	0.014
			[0.024]	[0.020]
Relative bond return (t)	2.354	5.363	1.065	3.454
	[4.243]	[5.108]	[4.235]	[4.838]
Relative bond return ($t-1$)	-10.318**	-4.747	-11.432**	-6.335
	[4.966]	[5.347]	[4.796]	[5.439]
Relative bond return ($t-2$)	-9.752**	-8.814**	-9.741**	-8.448*
	[4.143]	[4.032]	[4.198]	[4.191]
Funding ratio ($t-1$)	0.008*	0.010**	0.01	0.018*
	[0.004]	[0.005]	[0.007]	[0.010]
Net contributions ($t-1$)	0.375	0.38	0.18	0.177
	[0.234]	[0.235]	[0.324]	[0.332]
Required funding ratio ($t-1$)	0.008	0.006	0.007	-0.001
	[0.011]	[0.011]	[0.023]	[0.023]
Liability duration ($t-1$)	-0.022	-0.017	-0.099***	-0.082**
	[0.027]	[0.028]	[0.036]	[0.039]
Fund FE	No	No	Yes	Yes
Time FE	No	No	Yes	Yes
Obs.	2845	2845	2845	2845
First stage:				
Coefficient	1.175	1.320	2.491	2.219
t-stat	76.530	20.44	63.97	8.94

Table IA.6: **Margin call risk and selling of AAA medium-term bonds - MPS positive**: In Columns 1-3, we perform regressions of the percentage change in monthly individual-level nominal bond holdings on the lagged swap duration interacted with a dummy that indicates whether the bond is an AAA-rated government bond, denominated in euros, and with a remaining time to maturity above one during periods of interest rate surges and simultaneous positive effects of MPS on the 20-year OIS rate: 2015M6, 2022M4, 2022M9, and 2022M12. In Columns 4-6, we also interact with a dummy that indicates whether the bond has a remaining time-to-maturity that is below 7 years. Time, security, and fund-time fixed effects are included as indicated. Standard errors are clustered at the security level and reported in brackets. Significance: ***99%, **95%, *90%.

	$\%Hold$					
	(1)	(2)	(3)	(4)	(5)	(6)
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\}$	-0.104***	-0.084**	-0.098**	0.006	0.001	-0.018
	[0.039]	[0.040]	[0.041]	[0.055]	[0.052]	[0.052]
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\} \times \mathbb{1}\{T < 7\}$				-0.301***	-0.220***	-0.207***
				[0.078]	[0.074]	[0.075]
$Dur^S(t-1) \times \mathbb{1}\{T < 7\}$				-0.005	0.026	0.024
				[0.013]	[0.022]	[0.022]
$\mathbb{1}\{\text{AAA Bond}\} \times \mathbb{1}\{T < 7\}$				2.629***		
				[0.900]		
$Dur^S(t-1)$	0.034***	0.006		0.036***	-0.009	
	[0.006]	[0.006]		[0.010]	[0.014]	
$\mathbb{1}\{\text{AAA Bond}\}$	0.810*			-0.07		
	[0.439]			[0.549]		
$\mathbb{1}\{T < 7\}$				0.183		
				[0.193]		
Time FE	No	Yes	No	No	Yes	No
Security FE	No	No	Yes	No	Yes	Yes
Fund-Time FE	No	No	Yes	No	No	Yes
Obs.	213173	205254	205254	213173	205254	205254
R^2	0.00	0.25	0.26	0	0.25	0.26

Table IA.7: **Credit ratings**: This table reports the average credit rating of euro area sovereign debt over our sample period from 2012Q1-2022Q4. Credit ratings are from Fitch and numerical, ranging from 1 (lowest rating) to 21 (highest rating).

Country	Credit Rating	Country	Credit Rating
Greece	7	Estonia	16
Portugal	12	Slovakia	16
Latvia	13	Belgium	18
Lithuania	13	France	19
Italy	14	Austria	20
Spain	15	Finland	20
Slovenia	15	Germany	21
Ireland	15	Netherlands	21

Table IA.8: **Example margin call risk**: This table illustrates how using interest rate swaps can force pension funds to liquidate parts of their asset holdings when interest rates increase. The following five assumptions simplify the example: (i) The pension fund only invests in a broad stock index, a government bond, and receives the fixed rate in an interest rate swap; (ii) stocks have a duration of zero; (iii) the government bond has the same duration as the pension liabilities, which we set to 20 years; (iv) the interest rate swap has the same duration as the liabilities and the initial margin requirement is zero. There are two points in time: The initial investment and the time after a 1% increase in interest rates.

	Hedging with swaps		Hedging with bonds	
	(1) Initial position	(2) 1% rate increase	(3) Initial position	(4) 1% rate increase
Assets:	\$100	\$84	\$100	\$84
Cash	\$2.5	\$2.5	\$2.5	\$2.5
Bonds	\$55	\$44	\$80	\$64
Stocks	\$42.5	\$42.5	\$17.5	\$17.5
Swap notional: \$25	\$0	\$-5	–	–
Liabilities				
PV(L)	\$100	\$80	\$100	\$80
Assets - Liabilities	\$0	\$4	\$0	\$4