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 find interest rate hedging exposes pension funds to liquidity risk due to margin calls, which can exceed 15% of their total assets when rates rise. We first trace back swap usage to pension regulation and show pension funds with tighter regulatory constraints use swaps more aggressively. After quantifying margin calls, we show pension funds respond to these margin calls by selling safe and short-term government bonds. This procyclical selling adversely affects the prices of these bonds.

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 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, Klinger and Sundaresan, 2019). By contrast, little is known about the adverse effects of pension funds' hedging with derivatives—margin calls from derivatives positions pose a substantial liquidity risk and could potentially challenge the notion that pension funds are stable long-term investors.

To fill this void, we utilize unique regulatory data on Dutch pension funds that allow us to study the link between pension funds' derivatives positions, asset holdings, and asset prices. Focusing first on pension funds' hedging decisions, we find that pension funds with lower funding ratios use more interest rate swaps. While these swap positions reduce the interest rate risk faced by pension funds, they introduce substantial liquidity risk to the pension sector. In our sample, we find that substantial increases in interest rates expose pension funds to margin calls that can exceed 15% of their total assets. Pension funds respond to increasing interest rates by reducing their bond holdings and these reductions are more pronounced for funds with larger swap positions. During periods of significant interest rate hikes, pension funds primarily sell their safest and shortest term bonds, which has an adverse price impact. Hence, due to margin calls from their derivatives positions, pension funds' hedging decisions can even impact the shorter end of the yield curve.

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 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). The detailed information on pension fund liabilities, asset allocations, and derivatives positions combined with the fact that more than 70% of the Dutch pension funds use interest rate swaps makes the Dutch pension system an ideal laboratory for investigating the link between derivatives usage and asset holdings.

As a starting point of 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, pension funds primarily use swaps rather than bonds to hedge the interest rate risk of their liabilities. Finally, we estimate that the median margin call associated with a one percentage point increase in interest rates equals 7.52% of the pension funds' AUM. This estimate ranges up to a 95th percentile of 19.3%, exceeding the pension funds' cash holdings by several orders of magnitude.

We next derive and test three hypotheses. Our first hypothesis is that pension funds use more interest rate swaps when they face tighter regulatory constraints because it allows them to hedge against future losses while maintaining their tactical asset allocations. Our proxy for regulatory constraints is the funding gap, defined as the difference between the funding ratio required by regulators and a fund's observed funding ratio (the ratio between the present values of its assets and liabilities). Pension funds with a wider funding gap increase their swap positions, which reduces the volatility of their funding ratios due to fluctuations in interest rates. However, these increased swap positions expose pension funds to more *liquidity risk* due to larger margin calls when interest rates increase.

Further examining the manifestation of liquidity risk, our second hypothesis is that pension funds respond to increasing interest rates by selling the most liquid parts of their asset portfolios. As a first test of this hypothesis, we examine how increasing swap rates affect pension funds' asset allocations. We find that pension funds sell fixed income securities when interest rates increase. This result is distinct from rebalancing driven by tactical asset allocations, which would prompt the pension fund to *purchase* fixed income securities. To attribute the selling of fixed income securities to margin calls, we interact the changes in swap rates with the lagged swap duration at the fund level. Our analysis shows that the reduction in bond holdings is driven by pension funds with longer swap durations that are more exposed to margin calls. 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.

Taking this analysis one step further, we investigate how pension funds respond to substantial liquidity shocks, measured as large increases in swap rates. We first document that pension funds sell cash-like assets, such as money market funds (MMFs), in response to rate hikes.[1] We next examine pension funds' asset holdings at the security level. We show that the most liquid assets held by pension funds are German and Dutch government bonds, which are the only Euro-denominated government bonds with a triple-A rating from all major rating agencies over the full sample period. Consistent with our hypothesis, we find that pension funds sold German and Dutch government bonds in response to margin calls. Specifically, the selling of triple-A bonds concentrates in bonds with maturities below five years, which we show are more liquid than longer-dated bonds.

Because pension funds are major investors in government bond markets, our third hy-

[1] This finding aligns with Ghio, Rousova, Salakhova, and Bauer (2023), who demonstrate 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).

pothesis 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, measured as the weighted average swap duration of the pension funds holding the 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 interest rate hikes. In terms of economic magnitude, we find that a one standard deviation increase in the margin call risk measure reduces bond returns at the short-end of the maturity spectrum by 6 basis points, or 12% of the average short-term bond returns during periods of interest rate hikes.

We conclude our price impact analysis by applying the granular instrumental variables (GIV) approach developed by Gabaix and Koijen (2020, 2022) to estimate the overall impact of pension funds' margin calls on government bond yields. Specifically, during August 2022 when the 3-year safe Euro yield rose by 87 basis points, our estimates show that 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 shows 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). The liquidity risk in our study arises due to a combination of two financial regulations that should enhance the stability of financial markets. First, regulators require 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 exposes swap users to liquidity risk through margin calls.

This adverse effect of the two regulations expands beyond the Dutch pension sector.

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 risk-based 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 Appendix C). In addition, 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).

Related Literature

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 (2022), Ellul, Jotikasthira, Kartasheva, Lundblad, and Wagner (2022), Koijen and Yogo (2021), Ge and Weisbach (2021), and Koijen and Yogo (2022). Sen (2022) 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 that hedging with interest rate swaps exposes pension funds to liquidity risk from margin calls that can ultimately lead to fire sales of (safe) assets. 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, Klinger and Sundaresan, 2019, Jansen, 2022, Khetan, Li, Neamtu, and Sen, 2023) by showing that pension funds' selling behavior can even affect the short-end of the yield curve.

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) show similar selling behavior for US mutual funds during the market turmoil in March 2020. Czech, Huang, Lou, and Wang (2021) focus on the same distressed period and show that UK institutions sold their domestic safe assets to meet margin calls on their short-dollar FX positions. Our study shows that pension funds meet margin calls from their swap positions by following a similar pecking order. In contrast to the previous literature, the pecking order unveiled in our study is not unique to extreme crisis episodes. Pension funds also follow the pecking order during episodes of significant increases in interest rates.

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). 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 creating spillover effects in financial markets. A growing body of literature examines the UK pension crisis of September and October 2022, with studies such as Pinter (2023) offering a micro-structure analysis of liquidity dry-ups and adverse price movements in the Gilt market. While the UK pension crisis represents a pivotal case in our analysis, our study extends beyond this single episode. Instead, we provide a comprehensive understanding of pension liquidity risk, that is, how pension funds' balance sheet constraints prompt swap usage and how this swap usage, in turn, raises margin call risk and subsequent forced sales of safe assets during periods of interest rate hikes.

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 a set of 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.[2] Unlike 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.

[2]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).

1.1.1 Pension Regulation

To asses 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 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).[3] Second, the *required funding ratio* is based on a pension fund's risk profile. The required funding ratio is extracted from a 97.5% probability that the funding ratio does not drop below 100% within the next year and comparable to the value-at-risk (VaR) constraint in bank regulation. We provide additional details and sample calculations for the required funding ratio in Internet Appendix IA.2.

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 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, US pension funds can be substantially underfunded, but in these instances, the pension sponsor is ultimately liable for the pension liabilities.

While pension regulators in other jurisdictions (e.g., the US and Japan) focus primarily on the funding ratio, the required funding ratio is comparable to the risk-based capital re-

[3]More precisely, the first step in computing the discount rate involves extracting zero-coupon rates from swap rates and convert 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 (2022).

quirements that European insurance companies face under Solvency II. In our main analysis, we focus on the funding gap between funding ratio and required funding ratio. However, we show in the Appendix that our results remain consistent when we exclusively focus on the funding ratio.

1.1.2 Pension Risk Management

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

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 the 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.

To hedge this sensitivity to interest rates, the pension fund has three options. First, it can invest the majority of its assets in long-dated bonds and thereby match the duration of its assets and liabilities.[4] The drawback of this approach is that bonds have substantially

[4]Because pension regulation imposes that equities are not exposed to interest rate risk, pension funds need to use fixed income securities to hedge the duration risk of their liabilities.

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. Third, the pension fund can take a fixed receiver position in interest rate swaps to match the duration of its liabilities. While pension funds could combine these approaches for hedging their interest rate risk, we show later that interest rate swaps are their preferred hedging tool.

Hedging the 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 (margin requirement), it allows the pension fund to keep a large part of its investments in asset classes other than fixed income. Second, hedging with swaps has the same impact on the required funding ratio as purchasing (safe) Euro-denominated bonds. Because the discount rates used to value the pension liabilities are based on swap rates, interest rate swaps are an even better hedge than government bonds. In practice, as we demonstrate in the following section, pension funds do not fully hedge the interest rate risk of their liabilities. This means that most pension funds have a duration gap with their liabilities having a longer duration than their assets.

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 when 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 immediately after the contract is closed. The variation margin reflects the mark-to-market value of the swap. For instance, if interest rates increase, the value of the swap decreases and the fixed receiver must post additional variation margin. Hence, sharp increases in interest rates expose pension funds who use swaps for duration hedging to liquidity risk. The required amount of variation margin often exceeds the initial margin by several orders of magnitudes (Czech et al., 2021) and is the main driver of liquidity shocks during periods of interest rate hikes. Such liquidity shocks are especially severe if the variation margin is posted in cash.

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 derivatives 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 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 derivatives 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 sample comprises 255 distinct pension funds and 7993 fund-quarter observations.

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 5% percentile of 92% to a 95% percentile of 134%. The average funding gap, measured as the difference between the required funding ratio and funding ratio is 6%, ranging from a 5% percentile of -17% to a 95% percentile of 26%. Hence, pension funds face a funding gap for most fund-quarters in our sample and the funding ratio of most pension funds is well below 140%. The net contributions, defined as the pension contributions minus pension payments, equal on average 0.21% of AUM per quarter.[5] Finally, the average duration of the pension liabilities is 19 years and substantially higher than the average portfolio duration of approximately 12 years.[6]

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. Asset holdings do not "look through" underlying mutual fund investments, except for the largest two pension

[5]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.

[6]We infer the bond and swap durations from the regulatory filings. Details are in Appendix IA.3.

funds. For these pension funds, following Jansen (2022), we know pension funds' shares in mutual funds and we can use the reported holdings of mutual funds to obtain the underlying indirect holdings. 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 portfolio, 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.

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 73% in 2012 to 93% in 2022. For the 42 large pension funds, the fraction is even higher and equal to 100% for most of our sample period.[7] 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

[7] We further examine the decision to use interest rate swaps in the Appendix and find that the size of the pension fund is a main driver of swap usage, with larger pension funds being more likely to use swaps (Table IA.1).

for other derivative contracts (see Figure A1 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.[8]

[Insert Figure 1 near here]

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 20 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 8 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

[8] 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.

4 years.[9] Hence, Figure 2 suggests that pension funds adjust their portfolio duration using interest rate swaps and leaving their bond positions largely unchanged.

[Insert Figure 2 near here]

To highlight that the swap positions are used for hedging, we show in the Appendix (Figure A3) that pension funds' funding ratio would be more volatile if they had not used interest rate swaps. This result is similar to the findings of Sen (2022) for US insurance companies.

1.4.3 Risk of Margin Calls Exceeds the Cash Buffers

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 periods of substantial interest rate hikes. 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 hikes. This approach gives eight months with substantial interest rate hikes: 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 hikes in the Appendix (Figure IA.2 and Table A1).

Panel (a) of Figure 3 shows the distribution of realized margin calls during periods of interest rate hikes. The average realized margin call equals 4.5% of AUM and exceeds 10%

[9] 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.

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.[10] 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 report the margin calls they would receive when interest rates rise to the regulator directly. We illustrate the close link between our estimates and the reported numbers in the Appendix (Figure IA.1).[11]

[Insert Figure 3 near here]

2 Hypotheses

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

Klinger and Sundaresan (2019) link drops in long-dated swap rates to decreases in the funding status of DB pension plans, arguing that pension funds with 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 and the pension fund wants to keep both its tactical asset allocation and interest rate risk unchanged. The only way to do this is to hedge parts of its interest rate risk with new swap contracts. We illustrate this point with a numerical example and through an illustrative model in Appendix B. Hence, our first hypothesis is that pension funds hedge using interest rate swaps.

Hypothesis 1. *Pension funds with a worse funding status increase their swap usage.*

[10] Cash holdings include money market funds and (term) deposits with time to maturities of less than one year.

[11] The reported margin calls are typically somewhat lower than our proxy because some funds have buffers against margin calls in the form of cash holdings in a margin account.

This hedging reduces the adverse impact of falling interest rates but exposes the pension fund to the risk of margin calls when interest 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. Hence, sharp increases in interest 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. These liquidations are stronger for pension funds with larger swap positions. The second part of our hypothesis states that funds 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 interest rates, pension funds sell their safest and most liquid bonds first.

To test part (b) of Hypothesis 2, we assume that short-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.3 in the Internet Appendix, which highlights significantly lower bid-ask spreads for government bonds with less than five years to maturity.

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 tactical asset allocation. Hence, *lower* bond allocations in response to interest rate increases are not driven by the funds' rebalancing efforts. In addition, while rebalancing due to tactical 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, incorporating pension funds' swap positions into our analysis mitigates reverse-causality concerns. If lower fixed income allocations by pension funds were pushing swap rates up, we would not expect a stronger effect for pension funds with higher swap holdings.

Building on Hypothesis 2, we next note that pension funds are huge investors in the sovereign bond market. Hence, our final hypothesis is that their selling behavior during times of extreme interest rate hikes has an adverse price impact.

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

3 Swap Usage and Regulatory Constraints

In this section, we test Hypothesis 1 and link pension funds' swap usage to regulatory constraints. Figure 4 shows a binned scatter plot of changes in portfolio durations and lagged funding gaps. This is suggestive evidence in favor of Hypothesis 1. If the lagged funding gap is positive, that is, when pension funds have a worse funding ratio than required by regulators, pension funds with a positive funding gap tend to increase their portfolio duration as the funding gap widens. This correlation between funding gap and portfolio duration breaks down for funds with a higher funding ratio than required by regulators.[12]

[Insert Figure 4 near here]

We next study the relationship between changes in portfolio duration ($\Delta Dur_{i,t}$) and the lagged funding gap ($FGap_{i,t-1}$) in panel regressions of the following form:[13]

$$\Delta Dur_{i,t} = \beta_0 FGap_{i,t-1} \times \mathbb{1}\{FGap_{i,t-1} > 0\} + \beta_1 FGap_{i,t-1} + \beta_2 \mathbb{1}\{FGap_{i,t-1} > 0\} + \gamma C_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{i,t}. \tag{1}$$

Guided by Figure 4, which suggests the lagged funding gap is only relevant for pension plans with a funding gap, we study the link between asset duration and funding gap separately for funds with a positive funding gap ($\mathbb{1}\{FGap_{i,t-1} > 0\}$). The time-varying fund level controls ($C_{i,t-1}$) include the lagged duration of the pension liabilities, the lagged logarithm of the funds' AUM, and lagged net contributions (% AUM). Column (1) of Table 2 confirms the motivating evidence from Figure 2; funds with larger funding gaps expand their portfolio duration, but only if they face a funding gap. Column (2) shows the results including fund-fixed effects as additional control. As we can see from that column, the link between the lagged funding gap and changes in 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 gap is 15.66%. Hence, Column (2) shows that a one standard deviation increase in the funding ratio of an underfunded pension fund increases its portfolio duration by 0.24 (= 1.530 × 0.1566) years.

[12] In addition, Figure A4 illustrates the strong negative relation between the cross-sectional averages of funding ratios and margin call risk over time.

[13] We cluster the standard errors in this analysis at the fund level. The results remain valid 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).

[Insert Table 2 near here]

A critical question for our analysis is whether these increases in portfolio duration are driven by swap usage or purchases of longer-dated bonds. To examine this question, we replace changes in portfolio duration with changes in swap duration on the left-hand side of Equation (1). This test corroborates the suggestive evidence from Figure 2 that most of these fluctuations come from changes in swap durations. Column (3) of Table 2 shows that the link between lagged funding gap and swap duration is statistically significant and of comparable magnitude to the coefficients from Column (1). In addition, adding fund fixed effects as controls, Column (4) shows that the economic magnitude nearly doubles with a one standard deviation increase in the funding gap increasing the swap duration by 0.27 ($= 1.701 \times 0.1566$) years. By contrast, Columns (5) and (6) suggest no significant link between lagged funding gap and changes in the duration of the asset portfolio.

While we focus on changes in swap durations for our main analysis, one possibility would be using the level of swap durations instead of changes. Figure A2 shows the association between the lagged funding gap and the level of the swap duration is even more pronounced. In addition, our analysis is robust to three variations that we discuss in the Appendix of the paper. First, Table IA.2 shows that our results are robust to a regression specification that includes the lagged funding gap without conditioning on whether a pension fund is underfunded. Second, we show that the results are robust to using the funding ratio instead of the funding gap in Table IA.3. Finally, in Appendix Table IA.5, we address the endogeneity issue that arises when using contemporaneous changes in the funding gap by applying an IV methodology.

To conclude our analysis, we show pension funds with tighter regulatory constraints do not increase their cash holdings. Hence, the observed increases in swap positions expose pension funds to more liquidity risk from margin calls. To make this point, Figure 5 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 regulatory constraints *reduce* their cash holdings. Following up on this result, Table A2 in the Appendix confirms that underfunded pension plans have lower cash holdings.

[**Insert Figure 5 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 to pension funds' fixed income holdings. Afterwards, we focus on large interest rate hikes 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, but while this is a relatively small fraction, in terms of AUM we cover between 85-90% of the

Dutch pension assets.

We run panel regressions of the following form:

$$\frac{Net\ Buys_{i,t}}{AUM_{i,t-1}} = \beta_0 \Delta r_t^{Swap} + \beta_1 \Delta r_t^{Swap} \times Dur_{i,t-1}^{Swap} + \beta_2 Dur_{i,t-1}^{Swap} + \gamma C_{i,t-1} + \alpha_i + \varepsilon_{i,t}, \tag{2}$$

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 our proxy for fund i's margin call risk in period $t-1$. $C_{i,t-1}$ are time-varying fund-level controls and include a fund i's lagged funding gap, duration gap, and net contributions. To account for rebalancing effects in our analysis, we control for the relative performance of a fund's equity compared to its fixed income portfolio. Specifically, for each pension fund i, we calculate the change in the hypothetical allocation to equities if the fund did not trade at time t as follows:

$$\Delta w_{i,t}^{EQ,hyp} = \frac{w_{i,t-1}^{EQ}(1 + r_t^{MSCI})}{w_{i,t-1}^{EQ}(1 + r_t^{MSCI}) + (1 - w_{i,t-1}^{EQ})(1 + r_t^{IG})} - w_{i,t-1}^{EQ}, \tag{3}$$

where $w_{i,t-1}^{EQ}$ equals the equity allocation of pension fund i at time $t-1$, r_t^{MSCI} the return on the MSCI Index at time t, and r_t^{IG} the return on the European Investment Grade Bond Index at time t. A positive value of Equation (3) indicates outperformance of the equity portfolio over the bond portfolio, leading to a mechanical increase in the equity allocation. Conversely, a negative value indicates underperformance of the equity portfolio, leading to a subsequent decrease in its allocation. To capture the potential delay in rebalancing, our analysis includes both the current and lagged values of these hypothetical changes in the equity allocation.

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 (2) 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 hikes, pension funds' fixed income allocations drop by 0.30%. In contrast to rebalancing due to the tactical 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 tactical 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 equity allocation is insignificant, while its lag is positive and statistically significant at the 5% significance level. Hence, higher equity returns induces pension funds to buy fixed income and move away from stocks in the next period 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 (3) and (5) show that the interaction term is statistically significant with the expected sign. By contrast, changes in the swap rate are not statistically significant. To absorb any unobservable fluctuations in financial markets or the economy, we next add time-fixed effects as 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 can see from Columns (4) and (6) in Table 3, the effect of the interaction term remains virtually unchanged after controlling for time-fixed effects. By contrast, our rebalancing proxies turn insignificant as it is primarily influenced by stock and bond market returns, which are subsumed by the time fixed effect. The cross-sectional results alleviate the potential concern that changes in swap rates are endogenous to pension funds' portfolio rebalancing.

4.2 Selling Behavior During Interest Rate Hikes

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. To capture margin calls, we focus on months in which the maximum ten-day change in swap rates exceeds 40 basis points. We define these eight event months 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 A5 of the Appendix confirms that pension funds sell their MMF shares during periods of substantial interest rate hikes. 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 reveals that Dutch pension funds use the sales of MMF shares as one of the key primary sources to obtain liquidity (DNB and AFM, 2024).[14] However, as the median pension 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 and we therefore introduce an indicator variable $\mathbb{1}\{\text{AAA}_{j,t}\}$ that equals one if security j is a government bond with a triple-A rating from all three major rating agencies in period t and if security j is denominated in euro. 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.6 in the Internet Appendix for an overview of the credit ratings in our sample). Furthermore, since short-term bonds are more liquid than long-term bonds, we expect selling to be concentrated at the short-end of the maturity spectrum. Hence, we introduce an indicator variable $\mathbb{1}\{T \leq 5\}_{j,t}$ that equals one if the bond has a remaining time to maturity that is lower or equal to five years.

To understand which parts of their fixed income portfolios pension funds liquidate when

[14] As pointed out in stress-tests conducted by DNB and AFM (2024), another key source to obtain liquidity is through repo transactions. 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.

they face margin calls, we examine security-level changes in the notional amounts for each fund in each of the eight event months. As a starting point of our analysis, we compare the percentage changes in the notional amount of triple-A Euro-denominated bonds to the percentage changes of all debt for each fund in our sample. As shown in Figure 6, we observe larger declines in holdings for triple-A rated Euro-denominated bonds compared to other bonds.

[Insert Figure 6 near here]

We next run panel regressions of the following form:

$$\Delta\% Hold_{i,j,t} = \beta Dur^{Swap}_{i,t-1} \times \mathbb{1}\{\text{AAA}_{j,t}\} \times \mathbb{1}\{T \leq 5_{j,t}\} + \gamma C_{i,j,t} + \delta_j + \alpha_{i,t} + \varepsilon_{i,j,t}, \quad (4)$$

where $\Delta\% Hold_{i,j,t}$ captures the percentage change of the holding of fund i in security j, measured over each hike 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 lagged swap duration and the two indicators separately, δ_j are stock-fixed effects, and $\alpha_{i,t}$ are fund-time fixed effects.[15] 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

[15] 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 reason is that pension funds likely buy and sell in similar directions. 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).

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 short end of the maturity spectrum, we also examine the interaction with $\mathbb{1}\{T \leq 5\}_{j,t}$ 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 five years to maturity by up to -1.04% $(= 5.71 \times (-0.031 - 0.151))$.

[Insert Table 4 near here]

The finding that pension funds mostly sell short-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 short-term bonds.

4.2.1 Equity Sales in Response to Margin Calls?

To conclude our analysis of pension funds' response to margin calls, note a qualitative difference between the eight periods of interest rate hikes. The rate hikes in 2022 mark a persistent change in monetary policy, while the hikes in 2015 and 2020 are transitory spikes. Persistent interest rate hikes 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 7 near here]

Figure 7 illustrates the qualitative differences in the eight rate hike episodes. While pension funds sell parts of their bond portfolios during all rate hike episodes, equity sales are unique to the hikes in 2022. 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, 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 significantly lower equity allocations than their Dutch counterparts,[16] which likely contributed to a more pronounced sell-off in the UK gilt market in 2022.

5 Price Impact of Pension Funds

Because Dutch pension funds are large investors in the safe Euro-denominated government bond market (Jansen, 2022), our third hypothesis is that their bond sales resulting from 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 us a GIV approach to examine the aggregate effect of margin calls on safe Euro bond yields.

[16] 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).

5.1 Cross-Sectional Bond Price Effects

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

$$MC_t^b = \sum_{i=1}^{K_t^b} Dur_{i,t}^{Swap} \frac{N_{i,t}^b}{\sum_{k=1}^{K_t^b} N_{k,t}^b}, \tag{5}$$

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 five 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 8 shows a binned scatter plot of our bond-level measure of margin call risk against the ten-day returns of short-term bonds ($T \leq 5$) 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 hikes.

[**Insert Figure 8 near here**]

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

$$r_t^b = \alpha + \beta MC_{t-1}^b + \gamma C_t^b + \varepsilon_t^b, \tag{6}$$

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 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. In terms of economic magnitude, a one standard deviation increase in the margin call risk measure (=4.50) reduces bond returns by 6 basis points, or 12% of the average return (= - 0.52%) during periods of substantial interest rate increases.

[Insert Table 5 near here]

We next investigate if the results in Column (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:

$$CF_t^b = \frac{1}{K_t^b} \sum_{i=1}^{K_t^b} Dur_{i,t}^{Swap}. \tag{7}$$

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 durations across pension funds. In particular, the correlation between CF_t and MC_t is only 0.59. 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.

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, using the Granular Instrumental Variables (GIV) approach developed by Gabaix and Koijen (2020). 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.[17] We supplement these data with monthly holdings of international mutual funds from Morningstar. This expanded sample captures 2,214 institutions that jointly hold 12% of all outstanding safe Euro debt, on average. Figure A6 in the 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

[17]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.

of the following form:[18]

$$\Delta q_{i,t} = \alpha_t + \alpha_i + \beta_{0,i} GDPgrowth_t + \beta_{1,i} \Delta Inflation_t + \beta_{2,i} \Delta Fiscal_t + \beta_{3,i} t + \Delta \check{q}_{i,t}. \quad (8)$$

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 Germany counterparts, using their respective total debt outstanding as weights.

Because our holdings data are monthly and we only observe quarterly GDP and inflation, we estimate GDP growth (inflation changes) by allocating one-third of the growth (inflation 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 (8). 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 A6 in the 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:

$$\begin{aligned} \Delta Yield_t &= MZ_t + \gamma_0 GDPgrowth_t + \gamma_1 \Delta Inflation_t + \gamma_2 \Delta Fiscal_t \\ &+ \lambda_1 PC_{1,t} + \lambda_2 PC_{2,t} + \lambda_3 PC_{3,t} + \alpha + \varepsilon_t. \quad (9) \end{aligned}$$

[18]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.

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. Before using the GIV procedure, Column (1) shows the results when we simply use the weighted sum of actual changes in holdings instead of the residual changes. Because of confounding factors, we do not detect a statistically significant link between changes in holdings and bond yields. Examining the GIV next, Columns (2) to (6) 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 result remains virtually unchanged when controlling for two or three of the principal components.

[Insert Table 6 near here]

As a final step, we link our 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. We quantify the liquidity risk from margin calls that arises from swap usage and show that realized margin calls range from 4.5% to 15% of pension funds' total AUM. Furthermore, we show that this margin call risk introduces procyclical investment behavior with pension funds selling fixed income securities when interest rates rise. During periods of extreme interest rate hikes, pension funds sell safe government bonds and this selling pressure adversely impacts the prices of these bonds.

The results of our study have relevant implications for pension funds and policymakers. The combination of capital requirements for defined benefit (DB) pension funds—which are intended to make these funds safer—and mandatory collateral requirements of interest rate swaps have the unintended consequence of introducing liquidity risk for pension funds. This finding challenges the traditional view that pension funds are long-term investors immune to liquidity risk. Additionally, contrary to the common belief that decreases in interest rates are undesirable for long-term investors, our results reveal that abrupt increases in interest rates also have adverse consequences.

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.

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.

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.

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.

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).

Gabaix, X. and R. S. Koijen (2020). Granular instrumental variables. Working paper, National Bureau of Economic Research.

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.

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.

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. (2022). Long-term investors, demand shifts, and yields. Working paper, Tilburg University.

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.

Klinger, 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. 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.

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.

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

Sen, I. (2022, 10). 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.

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

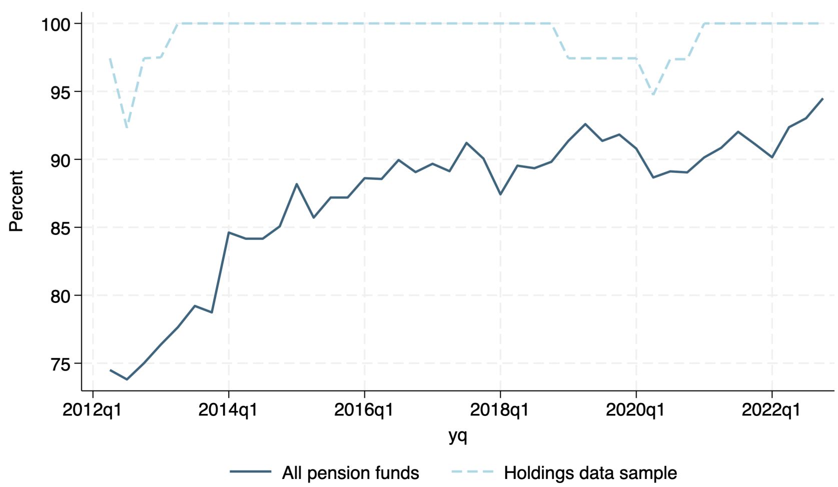
U.K. Parliament (2022). Financial markets stability: Volume 825: debated on thursday 3 november 2022. Technical report.

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

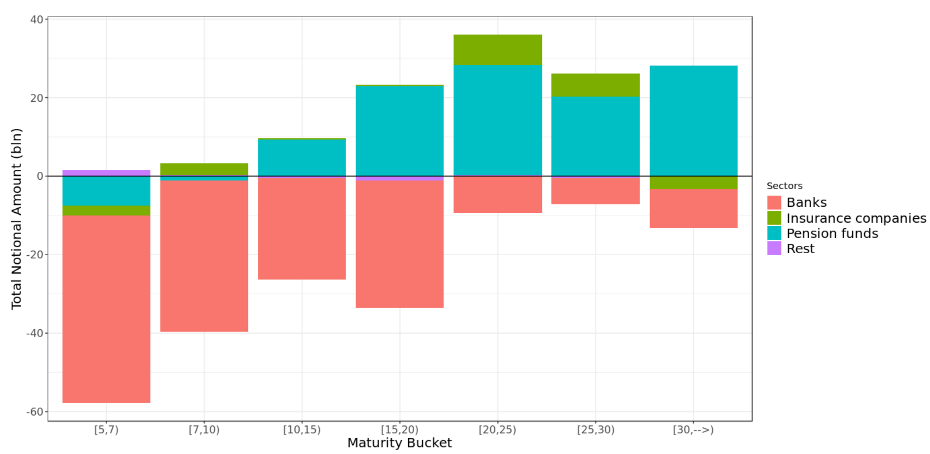
Figures and Tables

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 interest rate 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), assets (blue solid line), and total portfolio over time (purple dashed line). The total portfolio duration equals the sum of the asset and swap duration. The quarterly sample period is 2012Q1-2022Q4.

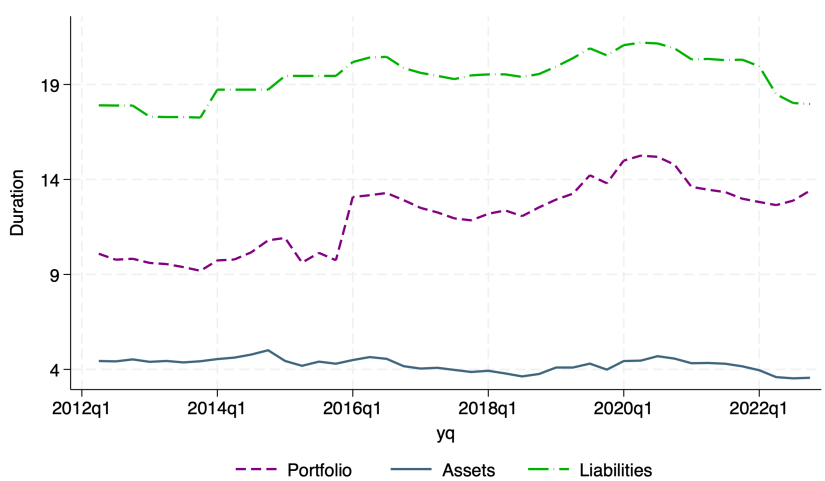
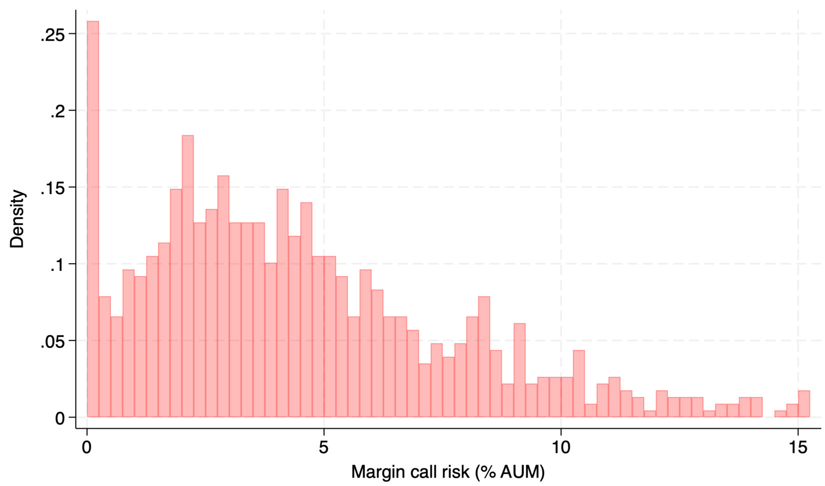
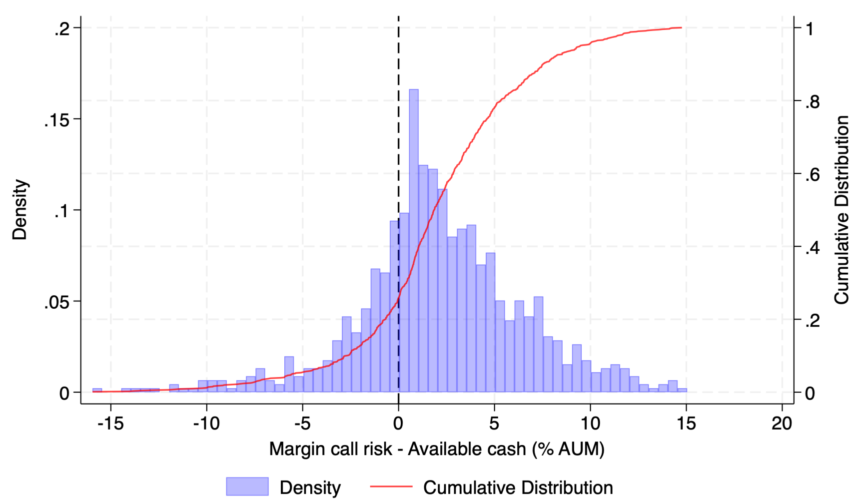


Figure 3: **Margin call risk versus available cash**

Panel (a) shows the distribution of realized margin calls relative to AUM for each pension fund during periods of interest rate hikes (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 hikes. 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 and (term) deposits with time to maturities of less than one year.



(a) Realized margin calls



(b) Realized margin calls minus available cash

Figure 4: **Portfolio duration and lagged funding gap**

This graph plots the lagged funding gap (required minus actual funding ratio) against the change in the 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.

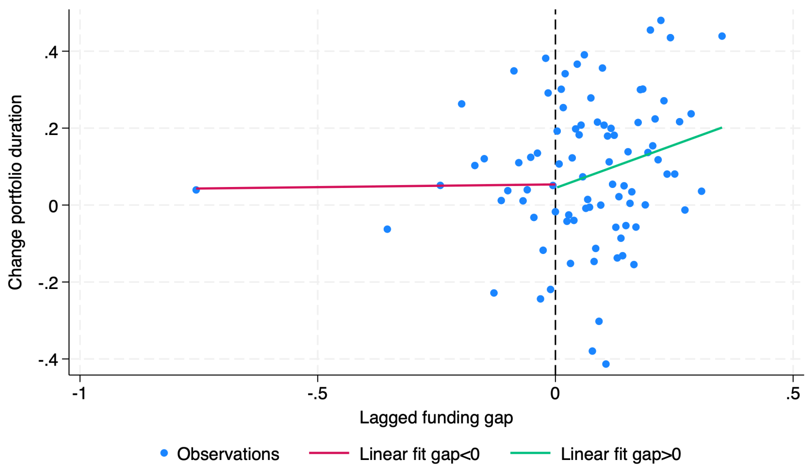


Figure 5: **Cash allocation and the funding gap**

This graph plots the lagged funding gap (required minus actual 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.

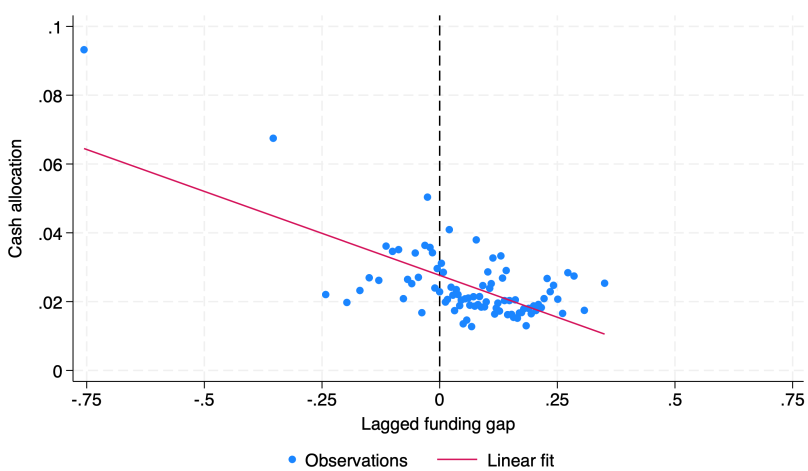


Figure 6: **Changes in bond holdings during periods of interest rate hikes**

This graph shows the percentage change in bond holdings during periods of interest rate hikes: 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).

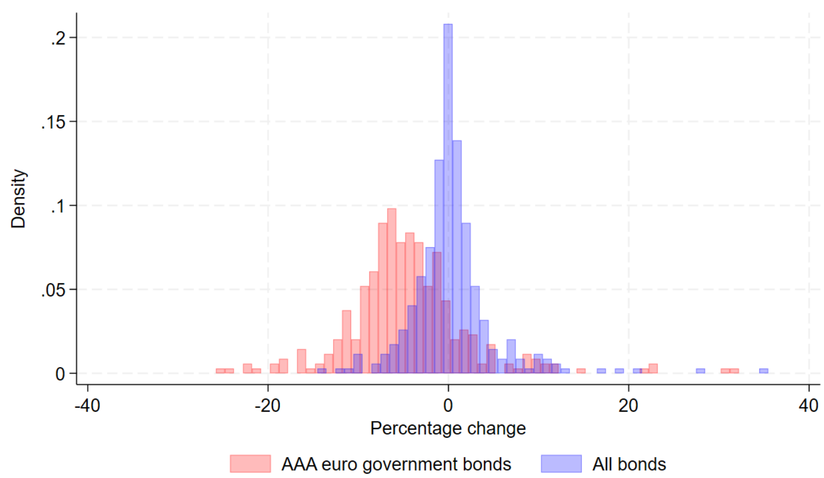
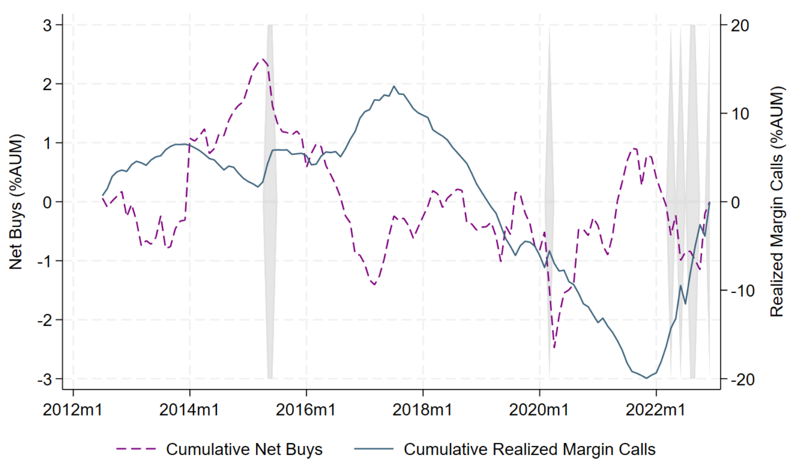
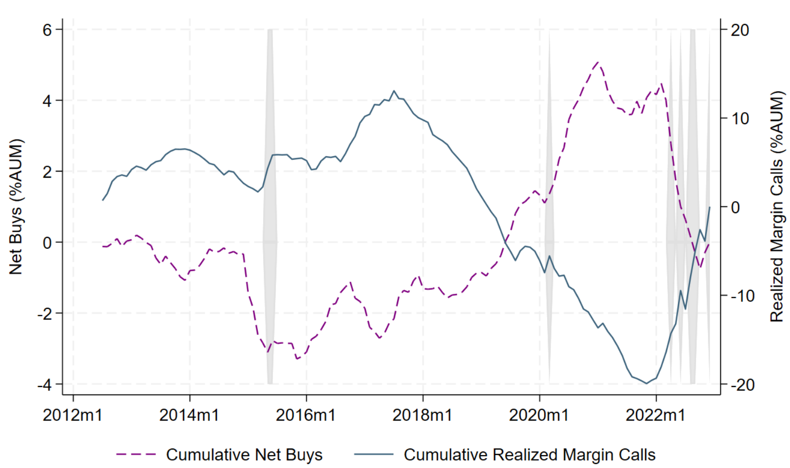


Figure 7: **Cumulative fixed income versus equity sales**

This figure plots the detrended cumulative distribution of aggregate net buys 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 of fixed income (equities) securities minus the total 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 8: **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 of 5 years or lower, orthogonal to the component of returns driven by time-to-maturity. We include all periods of interest rate hikes: 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.

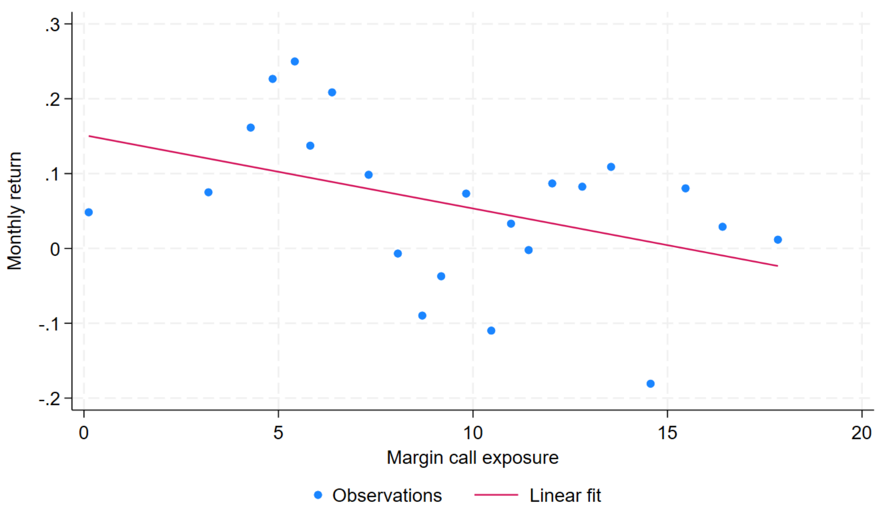


Table 1: **Summary statistics**: Panel A shows the AUM (billions), funding ratio (pp), required funding ratio (pp), funding ratio gap (pp), net contributions (% AUM), allocation to fixed income (pp), allocation to cash (pp), allocation to equities (pp), and duration of the liabilities, total portfolio, 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	N
AUM (bln)	6.70	33.73	0.06	0.76	24.07	7993
Funding ratio	110.80	15.91	92.46	108.70	134.40	7993
Required funding ratio	116.80	4.88	108.80	116.60	125.00	7993
Funding ratio gap	6.21	15.66	-17.27	7.74	26.07	7993
Net contributions (% AUM)	0.21	0.76	-0.73	0.08	1.61	7686
Allocation fixed income	55.25	19.03	19.82	56.23	88.03	7993
Allocation cash	2.42	4.19	-0.41	1.28	9.42	4921
Allocation equity	33.42	11.98	16.27	32.14	53.96	7974
Duration liabilities	19.24	3.82	13.60	18.90	25.80	7993
Duration portfolio	11.73	5.57	3.50	11.03	21.89	7992
Duration assets	4.29	2.40	0.98	3.91	9.18	7992
Duration swaps	8.61	5.71	0.80	7.54	19.30	6894
Panel B: Monthly Bond Holdings Data						
	mean	sd	p5	p50	p95	N
% Euro Area	70.04	18.52	35.91	70.77	100.00	5490
% Corporate bonds	34.07	20.78	0.00	34.06	69.09	5490
% Government bonds	65.93	20.78	30.91	65.94	100.00	5490
% Gov bonds Germany	31.67	18.55	5.51	29.34	66.66	5483
% Gov bonds Netherlands	20.86	18.97	0.00	18.43	58.62	5483
Panel C: Monthly Market Data						
	mean	sd	p5	p50	p95	N
German 10-year yield	0.53	0.79	-0.58	0.41	1.86	132
Euribor 20-year swap rate	1.37	0.81	0.05	1.40	2.62	132
Return MSCI Index	8.23	49.77	-92.56	15.05	81.56	132
Return IG Bond Index	1.40	17.55	-30.49	4.10	24.81	132

Table 2: **Funding constraints and swap usage**: We regress *changes* in portfolio, swap, and asset duration on the lagged funding gap interacted with a dummy that indicates whether the fund is underfunded at the same time (D^{UF}). The funding gap is defined as the required minus the actual funding ratio. Controls include the lagged liability duration, AUM, and net contributions. 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 × D^{UF} $(t-1)$	0.804***	1.530***	0.848**	1.701**	-0.127	-0.545*
	[0.244]	[0.503]	[0.357]	[0.858]	[0.164]	[0.301]
Funding gap $(t-1)$	0.075	0.283	0.02	0.048	-0.067	0.113
	[0.117]	[0.235]	[0.283]	[0.821]	[0.060]	[0.121]
D^{UF} $(t-1)$	-0.048	-0.013	-0.048	0.024	0.051*	0.041
	[0.053]	[0.071]	[0.064]	[0.087]	[0.030]	[0.034]
Liability duration $(t-1)$	0.011**	0.018	0.008	0.034	-0.002	-0.016
	[0.005]	[0.028]	[0.006]	[0.037]	[0.003]	[0.011]
Log AUM $(t-1)$	-0.01	-0.454**	-0.012	-0.321	0.015***	-0.039
	[0.008]	[0.207]	[0.008]	[0.231]	[0.004]	[0.099]
Net contributions $(t-1)$	-0.018	0.01	-0.013	0.024	0.039**	0.053
	[0.025]	[0.049]	[0.034]	[0.068]	[0.019]	[0.037]
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	7685	7685	6566	6562	7685	7685
R-squared	0.172	0.186	0.18	0.195	0.081	0.105

Table 3: **Bond holdings and maximum 10-day changes in swap rates**: 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 (Columns 3 and 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 2 and 5-6). Controls include the current and lagged changes in the hypothetical equity allocations as specified in Equation (3), funding gap, duration gap, and net contributions. Fund and time fixed effects are included as indicated. The monthly sample period is 2012M1-2022M12. Standard errors are clustered at the fund level and reported in brackets. Significance: ***99%, **95%, *90%.

	Net Buys/AUM					
	(1)	(2)	(3)	(4)	(5)	(6)
Δr^S	-0.806**		0.48			
	[0.324]		[0.523]			
$\mathbb{1}\{\text{High}\}$		-0.304**			0.165	
		[0.138]			[0.262]	
$Dur^S\ (t-1) \times \Delta r^S$			-0.167***	-0.165**		
			[0.060]	[0.064]		
$Dur^S\ (t-1) \times \mathbb{1}\{\text{High}\}$					-0.059**	-0.065**
					[0.027]	[0.027]
$Dur^S\ (t-1)$			-0.03	0.036	-0.047**	0.02
			[0.020]	[0.033]	[0.018]	[0.033]
Relative equity return (t)	-3.308	-4.32	-3.38	-10.167	-4.087	-10.723
	[3.001]	[3.125]	[3.206]	[18.037]	[3.233]	[18.110]
Relative equity return ($t-1$)	8.807**	7.573**	8.796**	14.092	7.647**	13.585
	[3.603]	[3.608]	[3.620]	[18.089]	[3.617]	[18.104]
Funding gap ($t-1$)	-0.376**	-0.414**	-0.406	0.791	-0.476	0.846
	[0.175]	[0.175]	[0.432]	[0.989]	[0.431]	[0.970]
Duration gap ($t-1$)	-0.007	-0.007	-0.049**	0.015	-0.046**	0.017
	[0.009]	[0.009]	[0.021]	[0.032]	[0.021]	[0.032]
Net contributions ($t-1$)	0.250***	0.254***	0.205	-0.113	0.217	-0.098
	[0.080]	[0.081]	[0.240]	[0.294]	[0.243]	[0.295]
Fund FE	No	No	Yes	Yes	Yes	Yes
Time FE	No	No	No	Yes	No	Yes
Obs.	4462	4462	4462	4462	4462	4462
R-squared	0.00	0.00	0.02	0.05	0.02	0.05

Table 4: **Margin call risk and selling of AAA short-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 and denominated in euros during periods of interest rate hikes: 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 equal or below 5 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%.

	Δ Nominal bond holdings					
	(1)	(2)	(3)	(4)	(5)	(6)
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\}$	-0.092***	-0.074**	-0.079***	-0.061**	-0.031	-0.042
	[0.028]	[0.030]	[0.030]	[0.030]	[0.031]	[0.032]
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA Bond}\} \times \mathbb{1}\{T \leq 5\}$				-0.095***	-0.151***	-0.132**
				[0.037]	[0.054]	[0.054]
$Dur^S(t-1) \times \mathbb{1}\{T \leq 5\}$				-0.017**	-0.007	-0.01
				[0.008]	[0.011]	[0.011]
$Dur^S(t-1)$	0.011***	-0.013***		0.018***	-0.011*	
	[0.004]	[0.004]		[0.005]	[0.006]	
$\mathbb{1}\{\text{AAA Bond}\}$	0.539*			0.464		
	[0.313]			[0.312]		
$\mathbb{1}\{T \leq 5\}$				-0.111		
				[0.113]		
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.	420118	415830	415830	420118	415830	415830
R-squared	0.00	0.14	0.15	0	0.14	0.15

Table 5: **Price impact of margin call risk**: The dependent variable are 10-day bond returns during periods of significant interest rate increases (2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12). The main independent variables are the lagged measure of margin call risk (MC (t-1)) as defined in Equation (5) in Columns (1) and (2) and the counterfactual proxy for margin call risk (CF (t-1)) as defined in Equation (7) in Columns (3) and (4). Controls include time-to-maturity (TTM), time since issuance (Age), coupon rates (Coupon), log total amount outstanding (Log(Outst)), an indicator whether the bond is inflation-linked ($\mathbb{1}$\{Inflation-Linked\}), and an indicator whether the bond is issued by the Netherlands ($\mathbb{1}$\{Dutch\}). In Columns (2) and (4) we also control for year-to-maturity fixed effects. Standard errors are clustered at the bond-level and reported in brackets. Significance: ***99%, **95%, *90%.

	Margin Call		**Counterfactual**	
	(1)	(2)	(3)	(4)
MC ($t-1$)	-0.011***	-0.013***		
	[0.004]	[0.004]		
CF ($t-1$)			0.001	-0.004
			[0.004]	[0.004]
TTM	-0.231***		-0.237***	
	[0.016]		[0.016]	
Age	-0.015***	-0.016***	-0.016***	-0.017***
	[0.004]	[0.004]	[0.004]	[0.005]
Coupon	0.048***	0.044***	0.057***	0.056***
	[0.017]	[0.017]	[0.019]	[0.019]
Log(Outst)	-0.019	-0.038	-0.026	-0.048
	[0.028]	[0.029]	[0.028]	[0.029]
$\mathbb{1}$\{Inflation-Linked\}	-0.198	-0.188	-0.147	-0.133
	[0.169]	[0.168]	[0.170]	[0.171]
$\mathbb{1}$\{Dutch\}	-0.01	-0.004	0.004	0.007
	[0.049]	[0.051]	[0.050]	[0.051]
Year-to-maturity FE	No	Yes	No	Yes
Obs.	466	466	466	466
R-squared	0.48	0.48	0.47	0.47

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. Q is defined as the weighted sum of actual changes in holdings and Z as the weighted sum of residual changes in holdings, i.e. the GIV. GDP growth and changes in (CIP) 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 lend 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 (8). 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)	(6)
Q	-0.06					
	[0.053]					
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	131
R-squared	0.01	0.03	0.05	0.06	0.06	0.07

Appendix

A Additional Details and Results

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

Figure A1 compares notional amounts of interest rate swaps to notional amounts of other derivatives used by Dutch pension funds.

[Insert Figure A1 near here]

Figure A2 plots the lagged funding gap against the *level* of swap durations, our proxy for pension funds exposure to margin call risk.

[Insert Figure A2 near here]

Figure A3 shows the cross-sectional average funding ratio of the pension funds in our sample over time. In addition, we construct a counter-factual funding ratio where we exclude fluctuations in the fair value of interest rate swaps.

[Insert Figure A3 near here]

Figure A4 shows the strong negative link between the cross-sectional average funding ratio and our proxy for margin call risk.

[Insert Figure A4 near here]

Figure A5 illustrates the link between our proxy for margin calls and fluctuations in MMF holdings.

[Insert Figure A5 near here]

Table A1 list all months during our sample period when we observe an increase in the 20-year swap rate exceeding 40 basis points.

[Insert Table A1 near here]

B Pension Funds and Swap Usage

In this section, we first provide additional insights into duration hedging with interest rates swaps using a simple numerical example. Afterwards, we develop a simple model to illustrate how pension funds benefit from using swaps.

B.1 Numerical Example

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 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 tactical 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 \$100. 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.

We next use an illustrative model to highlight that this link between swap usage and funding status holds for pension funds that are not restricted by their tactical asset allocation but instead optimize the risk-return profile of their assets and liabilities.

B.2 An Illustrative Model

We now use a simple static model to illustrate the link between duration hedging and funding gaps. 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 $PV(L) = LP$.[19] 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 $F = A - LP$.[20] 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:*

$$s = \frac{\mu - \mu_B}{\gamma(\sigma^2 + \sigma_B^2)} - \frac{\sigma^2}{\sigma^2 + \sigma_B^2}(A - LP). \tag{A.1}$$

We provide the proof of Proposition 1 and additional derivations in Section IA.4 of the Internet Appendix. Proposition 1 implies that pension funds use more swaps when they face tighter constraints in the form of lower funding ratios.

[19] 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.

[20] 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.

C 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.[21] EIOPA reports quarterly asset allocations and derivative positions of insurance companies at the country-insurance type level since 2017.

In our analysis, we focus on the life insurance sector. 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 consists of interest rate swaps.[22] In addition, we focus our analysis on the following countries: Austria, Denmark, France, Ireland, Netherlands, Norway, and Spain. The reason we exclude the other European countries is because of their limited use of interest rate derivatives (EIOPA, 2022). Indeed, we verify in the data that the countries we exclude have realized margin calls that are at most 0.25% of AUM.[23]

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 A7 summarizes the results. We find a negative relationship between realized

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

[22] We obtain this information from the EIOPA Financial Stability Report (EIOPA, 2022).

[23] We also exclude Belgium because of volatile asset allocations. The reason for this high volatility is that Belgium only has a few life insurance companies and there have been switches in the classification type over time, making it appear as if there have been large swings in and out of the Belgium life insurance sector.

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.

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 Austria was equal to 6.61, while it was 5.35 for Denmark (EIOPA, 2017). Hence, a rise in interest rates should, all else equal, lower the value of the bond portfolio more for Austria compared to Denmark. However, in the graph, we observe a larger reduction in the bond portfolio for Denmark than for Austria. 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 A1: **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.

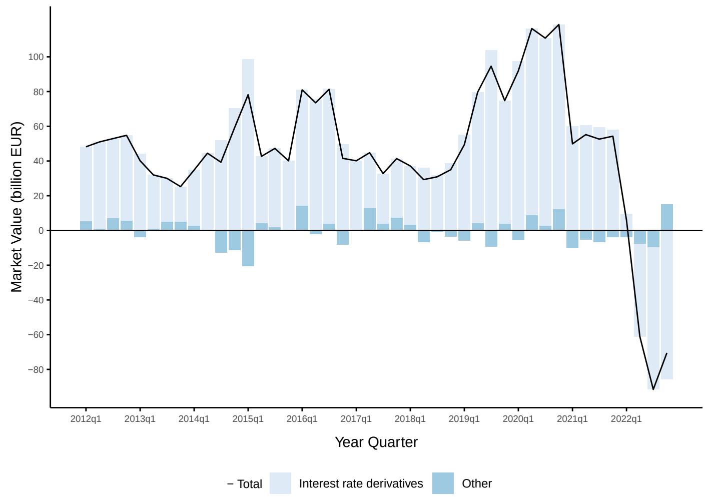


Figure A2: **Swap duration and the funding gap**

This graph plots the lagged funding gap (required minus actual funding ratio) against the swap 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.

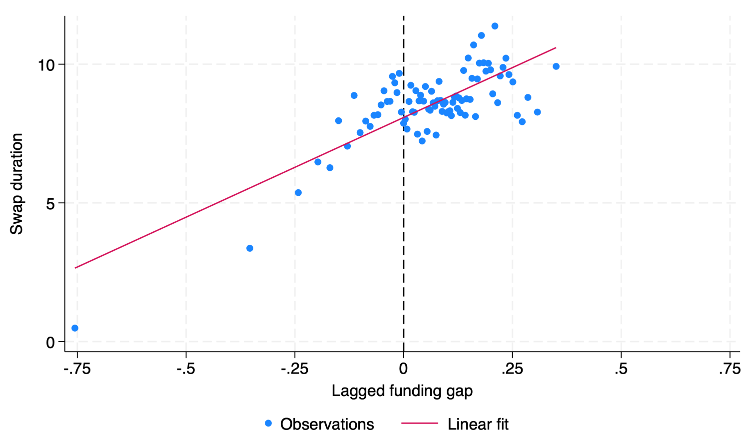


Figure A3: **Actual versus counterfactual funding ratios**

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.

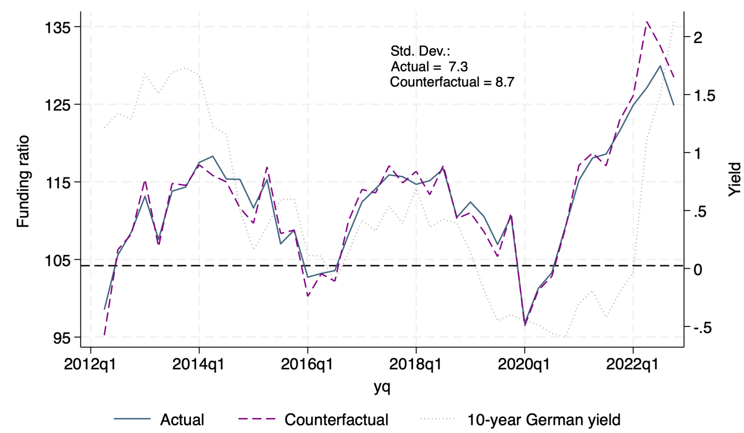


Figure A4: **Funding ratios and margin calls**

This figure shows a time-series of the sample 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.

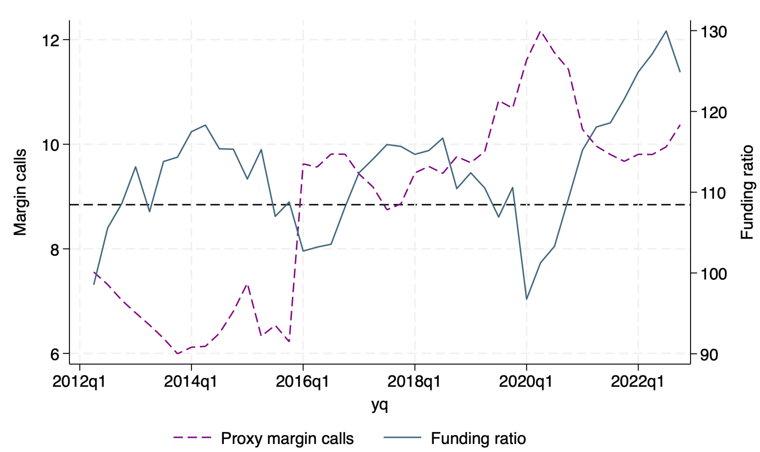


Figure A5: **Cumulative money market fund sales**

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 of MMFs 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.

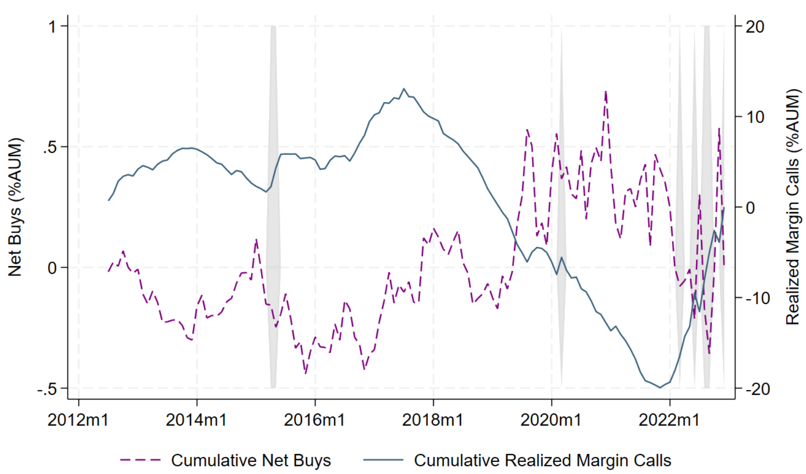
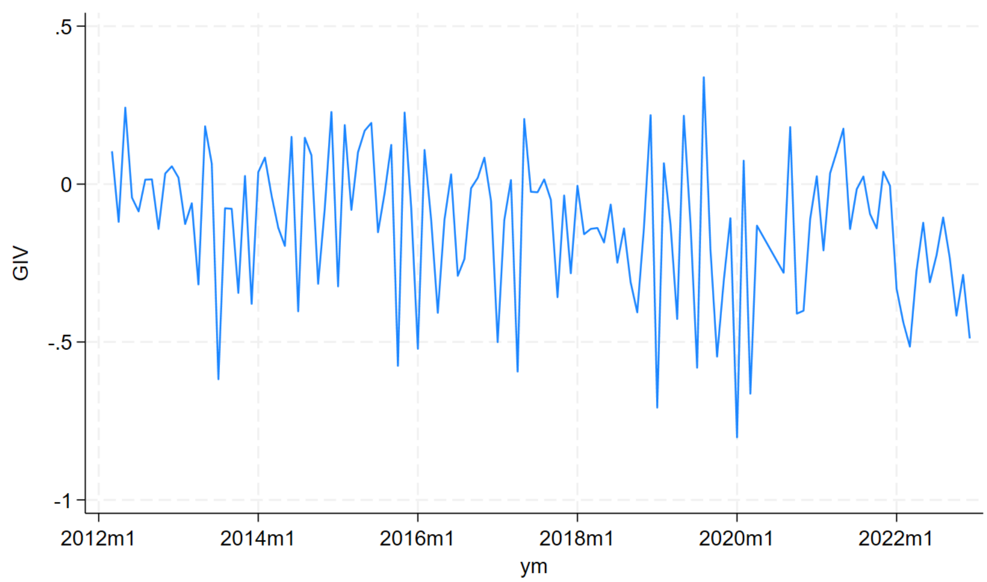


Figure A6: **GIV inputs**

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.

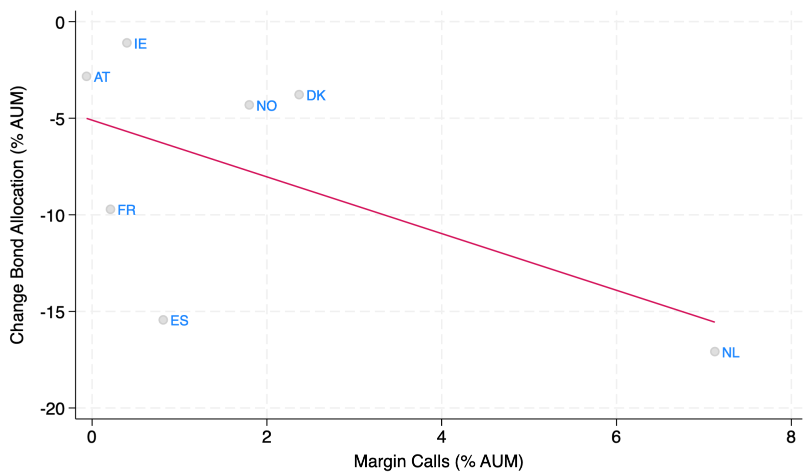
(a) Coverage



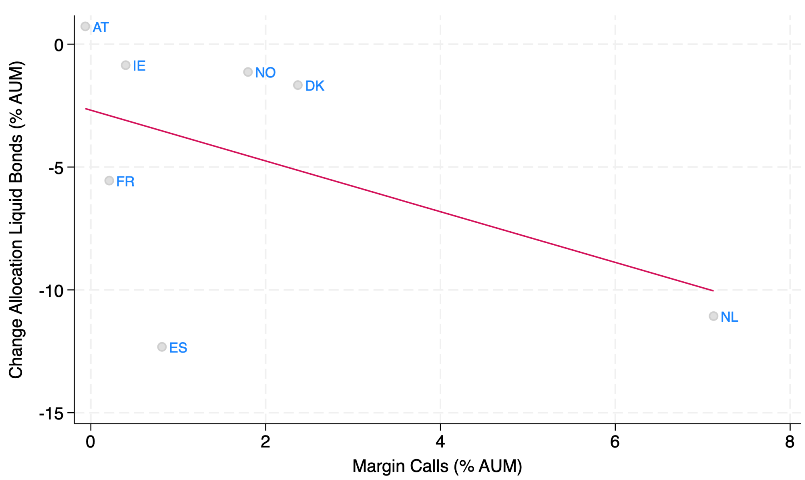
(b) GIV

Figure A7: **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: Austria (AT), Denmark (DK), France (FR), Ireland (IE), Netherlands (NL), Norway (NO), and Spain (ES). The data are from EIOPA public statistics and we focus on the country-level asset allocations of life insurers.



(a) All bonds



(b) Liquid bonds

Table A1: **Large swap rate rises 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.

Month	10-day Change	Monthly Change
May 2015	0.55	0.28
Jun 2015	0.44	0.40
Mar 2020	0.45	0.11
Apr 2022	0.42	0.54
Jun 2022	0.59	0.32
Aug 2022	0.55	0.62
Sep 2022	0.50	0.51
Dec 2022	0.53	0.47

Table A2: **Funding constraints and cash allocation**: We regress the allocation to cash on the lagged funding gap, and the lagged funding gap interacted with a dummy that indicates whether the fund is underfunded at the same time (D^{UF}). The funding gap is defined as the required minus the actual funding ratio. Controls include the lagged liability duration, AUM, and net contributions. 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 2015Q1-2022Q4. Significance: ***99%, **95%, *90%.

	Cash		**ΔCash**	
	(1)	(2)	(3)	(4)
Funding gap × D^{UF} $(t-1)$	-1.402	-9.309**	-0.258	1.201
	[3.821]	[4.222]	[0.888]	[1.006]
Funding gap $(t-1)$	1.06	2.368	-0.141	0.221
	[3.342]	[3.320]	[0.763]	[0.866]
D^{UF} $(t-1)$	-2.077***	-1.923***	-0.206	-0.290**
	[0.639]	[0.626]	[0.140]	[0.138]
Liability duration $(t-1)$	-0.128	-0.453*	-0.084	-0.035
	[0.206]	[0.247]	[0.053]	[0.055]
Log AUM $(t-1)$	5.965***	-0.291	-0.121	0.364
	[1.563]	[2.573]	[0.267]	[0.323]
Net contributions $(t-1)$	-0.889	-0.039	-0.12	-0.11
	[0.616]	[0.566]	[0.135]	[0.128]
Time FE	No	Yes	No	Yes
Fund FE	Yes	Yes	Yes	Yes
Obs.	4829	4829	4613	4613
R-squared	0.534	0.553	0.028	0.072

Table A3: **Price impact of margin call risk - placebo test**: We perform regressions of 10-day bond returns on the lagged measure of margin call risk during periods of interest rate hikes: 2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12, where we instead use equal weights for the margin call risk measure in Equation (5). Controls include time-to-maturity (TTM), time since issuance (Age), coupon rates (Coupon), log total amount outstanding (Log(Outst)), an indicator whether the bond is inflation-linked ($\mathbb{1}${Inflation-Linked}), and an indicator whether the bond is issued by the Netherlands ($\mathbb{1}${Dutch}). We show the results for all bonds (Column 1-2) and for bonds with remaining time-to-maturity below 5 years (Column 3-6). We also show the results separately for German bonds (Column 5) and Dutch bonds (Column 6). Year-to-maturity fixed effects are included as indicated. Standard errors are clustered at the bond-level and reported in brackets. Significance: ***99%, **95%, *90%.

	r_t^b					
	DE and NL debt				**DE debt**	**NL debt**
	All Maturities		$T \leq 5$			
	(1)	(2)	(3)	(4)	(5)	(6)
MC risk ($t-1$)	0.038***	0.041***	0.001	-0.004	-0.002	-0.005
	[0.007]	[0.008]	[0.004]	[0.004]	[0.005]	[0.008]
TTM	-0.269***		-0.237***			
	[0.009]		[0.016]			
Age	0.029***	0.018**	-0.016***	-0.017***	-0.034***	-0.008**
	[0.008]	[0.007]	[0.004]	[0.005]	[0.007]	[0.004]
Coupon	-0.116***	-0.073**	0.057***	0.056***	0.119***	0.021
	[0.036]	[0.029]	[0.019]	[0.019]	[0.027]	[0.024]
Log(Outst)	0.138**	0.154**	-0.026	-0.048	-0.019	-0.059
	[0.054]	[0.060]	[0.028]	[0.029]	[0.040]	[0.046]
$\mathbb{1}${Inflation-Linked}	-0.708***	-0.658***	-0.147	-0.133		
	[0.228]	[0.231]	[0.170]	[0.171]		
$\mathbb{1}${Dutch}	0.151*	0.198**	0.004	0.007		
	[0.087]	[0.081]	[0.050]	[0.051]		
Year-to-maturity FE	No	Yes	No	Yes	Yes	Yes
Obs.	804	803	466	466	334	132
R-squared	0.82	0.83	0.47	0.47	0.48	0.49

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 tactical 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 Details

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

Figure IA.1 illustrates the correlation between our proxy for margin call risk and the factual margin calls reported by pension funds.

[Insert Figure IA.1 near here]

Figure IA.2 shows a time-series of the daily level and changes of the 20-year swap rate over time.

[Insert Figure IA.2 near here]

Table IA.1 shows that in the cross-section liability duration and fund size are the predominant factors in determining whether a pension fund uses interest rate swaps.

[Insert Table IA.1 near here]

Using logistic regressions, Table IA.2 shows the results of regressing the changes in the swap duration on the lagged funding gap without conditioning on whether a pension fund faces a funding gap or not.

[Insert Table IA.2 near here]

Finally, Table IA.3 shows that our results are qualitatively similar when using the lagged funding ratio instead of the funding gap. Notice that the coefficient on the lagged funding ratio has the opposite sign: a higher (lower) funding ratio implies that the pension funds is better (worse) funded.

[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]

Robustness to Alternative Specifications

In the paper, We use the *level* of the lagged funding gap to explain changes in swap durations. An alternative specification would be to use changes in the funding gap. However, using contemporaneous changes in the funding gap is problematic because of endogeneity concerns. For instance, if a pension fund decides to lower (increase) it's 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 gap. More specifically, we run regressions of the following form:

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

where $\widehat{FGap}_{i,t}$ 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.[24]

Table IA.5 shows the results of this analysis. As before, we find a positive link between funding gap and portfolio duration with most of the portfolio adjustments coming from changes in the swap duration. In contrast to our previous results, we find a statistically significant link between funding gap and asset duration in this specification. However, the economic significance of the funding gap for asset duration is several orders of magnitude smaller compared to the swap duration.

[**Insert Table IA.5 near here**]

Table IA.6 shows the average credit ratings of different Euro-area sovereign bonds during our sample period

[**Insert Table IA.6 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

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

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 Proofs and Derivations

This internet appendix contains additional details omitted in the body of the paper.

To prove Proposition 1, we first note that the fund's optimization problem is given as:

$$\max_{a,b} \{\mathbb{E}[F] - \gamma Var(F)\}$$
$$\text{subject to: } a + b \leq A, a \geq 0, b \geq 0. \tag{IA.3}$$

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

$$F \leq \frac{\mu - r}{\gamma\sigma^2} + \frac{\mu_B - r}{\gamma\sigma_B^2}. \tag{IA.4}$$

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:

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

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.4) 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 $s = LP - b$.

■

Figure IA.1: **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 $\Delta r = +1\%$.

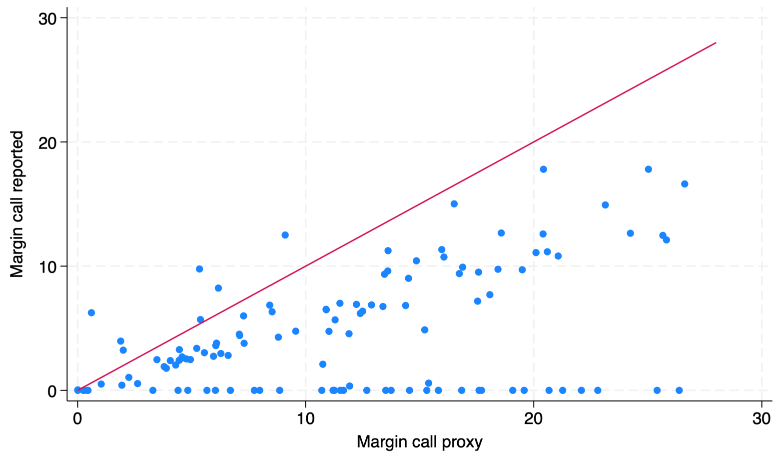
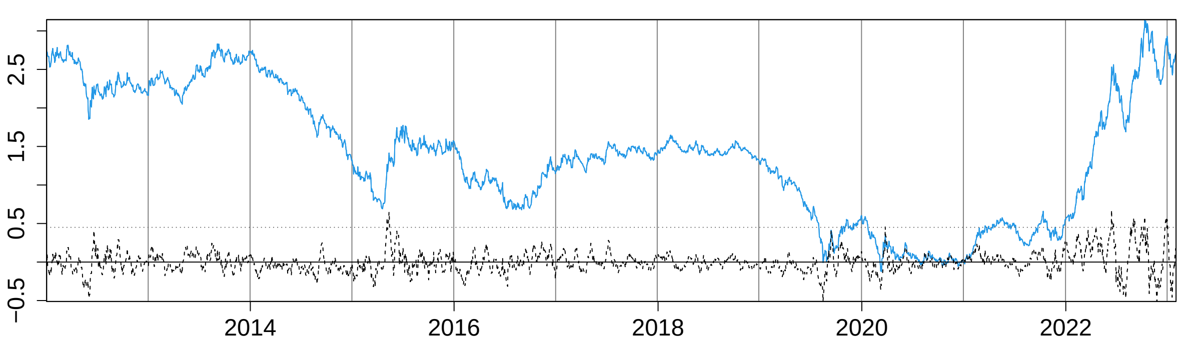


Figure IA.2: **Swap rates**

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 12-business-day period (which aligns with what we describe in the text). The figure shows that 12-day increases like we observed in March 2020 are rare. However, one comparable episode was May 2015. And we see lots of these episodes in 2022.



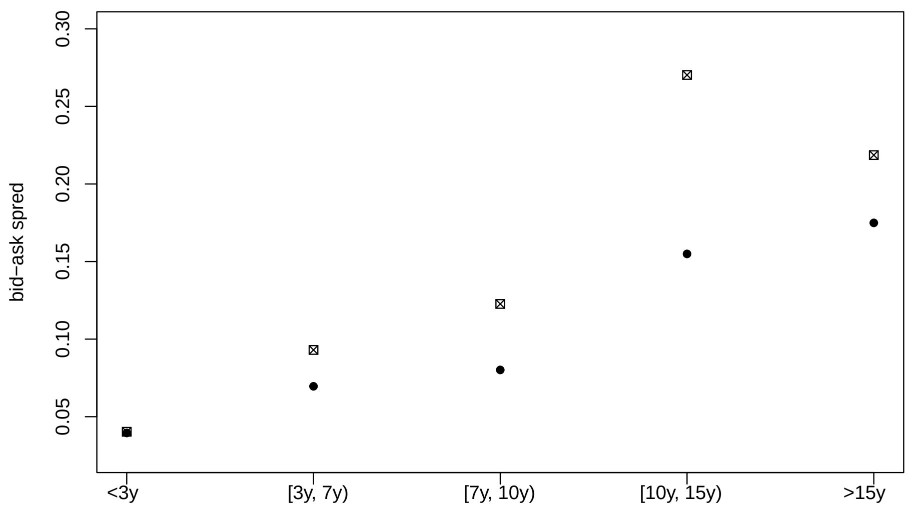


Figure IA.3: **Average bid-ask spreads for Dutch and German debt.** This figure shows the average bid-ask spreads of German and Dutch government bonds separated into five different maturity categories: (i) less than three years; (ii) three to seven years; (iii) seven to ten years; (iv) ten to 15 years; (v) more than 15 years. The circles correspond to averages for German government securities, the squares to Dutch government securities. The bid-ask spreads are obtained from Eikon.

Table IA.1: **The link between swap usage and fund characteristics**: We perform a cross-sectional regression of a dummy that equals one if the fund does not use swaps over the entire duration of our sample period, and zero otherwise; on the cross-sectional average fund characteristics: funding gap, liability duration, AUM, and net contributions. We report the results for a linear probability model (Column 1) and a logit model (Column 2). Robust standard errors are reported in brackets. Significance: ***99%, **95%, *90%.

	Linear prob	**Logit**
	(1)	(2)
Funding gap	0	-0.008
	[0.002]	[0.010]
Liability duration	-0.029***	-0.112*
	[0.009]	[0.060]
Log AUM	-0.049***	-0.255***
	[0.012]	[0.081]
Net contributions	0.019	0.104
	[0.052]	[0.271]
Obs.	255	255
R-squared	0.176	

Table IA.2: **Funding constraints and swap usage - no interaction term**: We regress *changes* in portfolio, swap, and asset duration on the lagged funding gap. The funding gap is defined as the required minus the actual funding ratio. Controls include the lagged liability duration, AUM, and net contributions. 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 $(t-1)$	0.305***	0.736***	0.374***	1.159**	0.005	0.009
	[0.092]	[0.265]	[0.133]	[0.491]	[0.041]	[0.095]
Liability duration $(t-1)$	0.012**	0.026	0.009	0.035	0	-0.01
	[0.005]	[0.028]	[0.007]	[0.038]	[0.002]	[0.012]
Log AUM $(t-1)$	-0.01	-0.461**	-0.01	-0.34	0.007**	-0.014
	[0.008]	[0.207]	[0.008]	[0.237]	[0.003]	[0.063]
Net contributions $(t-1)$	-0.022	0.001	-0.017	0.028	0.005	0.018
	[0.026]	[0.050]	[0.034]	[0.069]	[0.014]	[0.022]
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	7685	7685	6566	6562	7685	7685
R-squared	0.171	0.185	0.179	0.194	0.071	0.088

Table IA.3: **Funding constraints and swap usage - actual funding ratio**: We regress *changes* in portfolio, swap, and asset duration on the lagged funding ratio. The funding ratio is defined as the assets divided by the liabilities. Controls include the lagged liability duration, AUM, and net contributions. 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 ratio $(t-1)$	-0.287*	-1.008**	-0.298**	-0.902**	0.059	0.043
	[0.152]	[0.500]	[0.140]	[0.456]	[0.060]	[0.165]
Liability duration $(t-1)$	0.012*	0.026	0.011*	0.039	0	-0.009
	[0.007]	[0.036]	[0.007]	[0.037]	[0.002]	[0.011]
Log AUM $(t-1)$	-0.004	-0.257	-0.008	-0.301	0.005*	0.016
	[0.008]	[0.229]	[0.008]	[0.238]	[0.003]	[0.064]
Net contributions $(t-1)$	-0.017	0.034	-0.019	0.025	0.004	-0.001
	[0.035]	[0.065]	[0.034]	[0.069]	[0.016]	[0.028]
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	6566	6562	6566	6562	6566	6562
R-squared	0.202	0.216	0.179	0.193	0.073	0.094

Table IA.4: **Bond holdings and changes in swap rates**: This table regresses the monthly net purchases of bonds relative to AUM on the monthly change in the 20-year swap rate (Column 1) and the corresponding swap rate change interacted with the swap duration (Columns 3 and 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 2 and 5-6). Controls include the current and lagged changes in the hypothetical equity allocations as specified in Equation (3), funding gap, duration gap, and net contributions. Fund and time fixed effects are included as indicated. The monthly sample period is 2012M1-2022M12. Standard errors are clustered at the fund level and reported in brackets. Significance: ***99%, **95%, *90%.

	Net Buys/AUM					
	(1)	(2)	(3)	(4)	(5)	(6)
Δr^S	-0.540**		0.293			
	[0.235]		[0.350]			
$\mathbb{1}\{\text{High}\}$		-0.281**			0.235	
		[0.112]			[0.197]	
$Dur^S\ (t-1) \times \Delta r^S$			-0.107***	-0.104**		
			[0.038]	[0.040]		
$Dur^S\ (t-1) \times \mathbb{1}\{\text{High}\}$					-0.065**	-0.067***
					[0.024]	[0.024]
$Dur^S\ (t-1)$			-0.054***	0.011	-0.049***	0.019
			[0.017]	[0.033]	[0.018]	[0.033]
Relative equity return (t)	-1.322	-3.615	-1.781	-8.821	-3.462	-9.487
	[2.832]	[3.047]	[3.115]	[17.825]	[3.203]	[17.891]
Relative equity return ($t-1$)	8.224*	6.381	8.383*	22.534	6.736	21.734
	[4.597]	[4.339]	[4.693]	[17.879]	[4.391]	[17.797]
Funding gap ($t-1$)	-0.350*	-0.387**	-0.25	0.746	-0.359	0.754
	[0.178]	[0.178]	[0.432]	[0.999]	[0.446]	[0.992]
Duration gap ($t-1$)	-0.007	-0.007	-0.049**	0.015	-0.049**	0.016
	[0.009]	[0.009]	[0.020]	[0.032]	[0.020]	[0.032]
Net contributions ($t-1$)	0.251***	0.255***	0.227	-0.104	0.226	-0.107
	[0.080]	[0.081]	[0.244]	[0.301]	[0.243]	[0.298]
Fund FE	No	No	Yes	Yes	Yes	Yes
Time FE	No	No	No	Yes	Yes	Yes
Obs.	4462	4462	4462	4462	4462	4462
R-squared	0.01	0.01	0.02	0.05	0.02	0.05

Table IA.5: **Funding constraints and swap usage - IV**: We regress *changes* in portfolio, swap, and asset duration on *changes* in the funding gap, whereby we use the lagged allocation to equities times the return on the MSCI index as an instrument for the change in the funding gap. The funding gap is defined as the required minus the actual funding ratio. Controls include the change in liability duration, AUM, 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 gap	12.161***	20.490***	16.410***	26.463***	-0.685	-1.86
	[2.208]	[2.762]	[2.503]	[3.072]	[1.003]	[1.130]
Δ Liability duration	0.107*	-0.034	-0.01	-0.180**	0.062**	0.080**
	[0.064]	[0.065]	[0.063]	[0.084]	[0.030]	[0.034]
Δ Log AUM	1.486	1.899*	0.874	1.585	0.403	0.36
	[0.917]	[1.106]	[1.113]	[1.383]	[0.376]	[0.406]
Δ 10-year German yield	-0.307**	-0.107	-0.256	-0.057	-0.168***	-0.195***
	[0.131]	[0.146]	[0.157]	[0.181]	[0.056]	[0.060]
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	7724	7724	6607	6604	7724	7724
R-squared	-0.003	-0.141	-0.064	-0.276	0.008	-0.012
First stage:						
Coefficient	-0.005	-0.005	-0.005	-0.004	-0.005	-0.005
t-stat first stage	-23.52	-20.38	-21.78	-19.11	-23.52	-20.38

Table IA.6: **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