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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Abstract

Pension funds rely on interest rate swaps to hedge the interest rate risk arising from their liabilities. Analyzing unique data on Dutch pension funds, we show that this hedging behavior exposes pension funds to liquidity risk due to margin calls, which can be as large as 15% of their total assets. Our analysis uncovers three key findings: (i) pension funds with tighter regulatory constraints use swaps more aggressively; (ii) in response to rising interest rates, triggering margin calls, pension funds predominantly sell safe and short-term government bonds; (iii) we demonstrate that 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.
JEL: E43, G12, G18

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Introduction

Pension funds often hedge the interest rate risk arising from their liabilities by taking fixed receiver positions in long-dated interest rate swaps. Given the sheer size of the pension sector—total pension assets often exceed the gross domestic product (GDP) of the funds' home countries (OECD, 2022)—the market impact of pension funds' hedging decisions received substantial attention in the academic literature (e.g., Greenwood and Vayanos, 2010, Klinger and Sundaresan, 2019, Greenwood and Vissing-Jorgensen, 2018). By contrast, little is known about the risk of margin calls associated with pension funds' derivatives positions and whether such margin calls pose a substantial liquidity risk. Moreover, if margin calls trigger liquidity shocks, how do pension funds react to these shocks and do their reactions have an adverse effect on market prices?

To address these questions, we utilize unique regulatory data on Dutch pension funds and study the link between their derivatives positions, asset holdings, and asset prices. We first highlight one main driver of pension funds' derivatives usage: Pension funds with lower funding ratios use more interest rate swaps. These swap positions make pension funds susceptible to liquidity risk because increasing interest rates trigger margin calls. To investigate the manifestation of liquidity risk, we demonstrate that pension funds with larger swap positions reduce their bond holdings more than other funds when interest rates rise. Notably, during periods of significant interest rate hikes, these funds primarily sell the safest and most liquid bonds. We conclude by showing that those sales of safe and liquid bonds have an adverse price impact.

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) by 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 make the Dutch pension system and 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 duration risk of their liabilities.[1] Finally, we estimate the median margin call associated with a one percentage point increase in interest rates to equal 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. The first hypothesis posits that pension funds facing stricter regulatory requirements use more interest rate swaps. Our proxy for regulatory requirements 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). We find that pension funds with a wider funding gap increase their swap positions. This increase reduces the duration mismatch between assets and liabilities, enhancing the safety of the plans by stabilizing their funding ratios. However, this increased swap usage also exposes pension funds to heightened *liquidity risk*. As interest rates rise, funds with greater interest rate swap exposures face larger margin calls, potentially forcing them to liquidate substantial portions of their portfolios.

[1] Throughout we use the term "duration" as measure of the price sensitivity to interest rate risk. Pension regulation assumes that equities are not exposed to interest rate risk, and thus have zero duration.

Focusing on the adverse effect of swap usage, our second hypothesis is that pension funds respond to increasing interest rates by selling the most liquid parts of their asset portfolios. We test this hypothesis proceeding in two steps. First, we examine how increasing swap rates affect pension funds' asset allocations and 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 and find that the reduction in bond holdings is driven by pension funds with longer swap durations that are more exposed to margin calls.

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; consistent with the findings in (Ghio, Rousova, Salakhova, and Bauer, 2023; DNB and AFM, 2024). 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 7 years, which are arguably more liquid than longer-dated bonds.

Because pension funds are major investors in government bond markets, our third hypothesis is that their bond sales have an adverse price impact. To test this hypothesis, we construct a bond-level proxy for liquidity risk from margin calls, 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 with higher 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, in the context of the COVID-19 pandemic, our estimates show that sales by pension funds due to margin calls contributed to a 4.5 basis points rise in Dutch yields. This accounts for 10% of the total increase in yields during that period.

Our study shows that derivatives positions expose pension funds to liquidity risk due to margin calls. This result challenges the traditional view that pension funds, with their long-term investment horizons, act as stabilizers in financial markets (e.g., Timmer, 2018). The stress experienced by the UK pension sector in September and October 2022, marked by a sudden spike in British interest rates that triggered large margin calls and subsequent fire sales, vividly highlights the vulnerabilities that are inherent in pension funds' interest rate hedging strategies (e.g., U.K. Parliament, 2022; IMF, 2023). Despite this shocking episode, little is known about the prevalence of liquidity risk within the global pension system. Interpreting the results of our paper, the liquidity risk of Dutch pension funds arises due to a combination of two financial regulations that should enhance the stability of financial markets. First, pension regulators require funds to hedge their interest rate exposure and 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 is not limited to 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.

Related Literature

Our paper contributes to four 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. In a similar spirit, we show that regulatory constraints prompt pension funds to use more interest rate swaps. Our unique contribution to this literature is to highlight that, while hedging with interest rate swaps reduces pension funds' interest rate risk, it exposes pension funds to liquidity risk from margin calls that can ultimately lead to fire sales of (safe) assets.

Second, Greenwood and Vayanos (2010), Domanski, Shin, and Sushko (2017), Greenwood and Vissing-Jorgensen (2018), Klinger and Sundaresan (2019), and Jansen (2022) study the price impact of pension funds' demand for assets with long durations. Closest to our study, Klinger and Sundaresan (2019) show that the aggregate funding status of DB plans affects the pricing of interest rate swaps relative to Treasury bonds. We expand these results and quantify how the funding status of individual pension funds affects their demand for interest rate swaps. More importantly, using granular data, we construct a proxy for liquidity risk from margin calls at the individual fund level, allowing us to examine how this demand for swaps exposes pension funds to margin call risk and how this risk feeds back into a pension fund's asset allocation.

Third, 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 non-US 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. Instead of responding to investor redemptions or currency shocks, pension funds follow the pecking order during episodes of significant increases in interest rates.

Finally, we contribute to the broader literature on price impact and uninformed demand shocks (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 market. We contribute to this literature by showing that margin calls from derivative positions are another source of uninformed demand shocks creating spillover effects to financial markets. A growing body of literature examines the UK pension crisis of September 2022, with studies such as Pinter (2023) offering a microstructure 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 and provides a comprehensive understanding of pension liquidity risk, that is, how margin calls prompt pension funds to obtain liquidity by selling bonds.

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

As of December 2021, the total assets of the Dutch pension system equaled \$2.04 trillion, accounting for 53% of all pension assets in the Euro area (ECB, 2022) and corresponding to 209.5% of the Dutch GDP (OECD, 2022). 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

[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).

empirical analysis, where we pool all three types of pension funds.

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 Appendix A.

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

[3]More precisely, the first step in computing the discount rate involves extracting zero-coupon rates from interest rate swaps 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).

on the funding ratio, the required funding ratio is comparable to the risk-based capital requirements 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 its pension liabilities can expose a pension fund 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. To hedge this risk, 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. The drawback of this approach is that bonds have substantially lower returns than equities, which lowers the probability that the fund can provide full indexation in the future.[4] 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, the discount rates used to value the pension liabilities are based on swap rates and using interest rate swaps lowers the required funding ratio. Third, hedging through swaps has the same impact on the required funding ratio as purchasing (safe) Euro-denominated bonds. In practice, as we demonstrate in the following section, pension funds do not fully hedge the interest rate risk of their liabilities. 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

While interest rate swaps can be an ideal hedging tool, we now highlight the potential risks associated with using swap contracts. Despite traditionally being traded bilaterally in over-

[4] Throughout this paper, we use the term "duration" to capture the sensitivity of assets and liabilities to changes in interest rates. In addition, pension regulation assumes that equities are not exposed to interest rate risk, and thus have zero duration. Hence, pension funds need to use fixed income securities to hedge the duration risk of their liabilities.

the-counter (OTC) markets, 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 that can incur if a counterparty defaults immediately after the closing of a derivatives contract. The required amount of variation margin depends on the market value of the contract and a fixed receiver in an interest rate swap must post variation margin when interest rates increase. Sharp increases in interest rates can therefore expose pension funds to liquidity risk. Because the required amount of variation margin often exceeds the initial margin by several orders of magnitudes (Czech et al., 2021), it 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.

European pension funds have been mandated to exchange collateral on their derivative positions since mid-2012, but until June 2023 the specific type of collateral could be determined by the involved counterparties (European Parliament and Council, 2012). Moreover, while there was a push from bilateral trading toward central clearing (which involves cash collateral), pension funds were exempt from central clearing until June 2023 (ESMA, 2022). Although central clearing was not mandatory for pension funds during our sample period, in practice, most non-centrally cleared trades use cash as collateral (ISDA, 2017). There are at least three reasons why cash is the predominant form of collateral. First, bilaterally-cleared swaps are susceptible to discriminatory pricing (Cenedese, Ranaldo, and Vasios, 2020), and hence pension funds may prefer centrally-cleared contracts. Second, banks also prefer centrally cleared swaps because they allow multilateral netting and reduce the associated X-Value Adjustments (XVA), thereby lowering regulatory costs (Cenedese et al., 2020). Finally, as explained in Czech et al. (2021), 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). These granular data on all three types of balance sheet items make the Dutch pension system an ideal laboratory to study the feedback from pension funds' derivatives usage to their asset allocations.[5]

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 258 distinct pension funds and 8018 fund-quarter observations.

Table 1 contains summary statistics of our sample. The average pension fund has €6.68 billion in AUM and allocates 55% of its portfolio to bonds and 33% to equities. The average funding ratio is 110% 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 funding ratio and required funding ratio is 6%, ranging from a 5% percentile of -17% to a 95% percentile of 26%. Hence most fund-quarters in our sample are for pension funds with a funding gap and the funding ratio of most funds in our sample is well below 140%. Finally, the average duration of the pension liabilities is around 20 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.

[5] Similar data granularity is also available for US insurance companies (e.g., Sen (2022)).

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

This sample comprises only 42 pension funds but covers between 85% and 90% of the total AUM of Dutch pension funds.

[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] Additionally, Figure A6 in the Appendix illustrates that the interest rate swap portfolio is the predominant derivative category used by pension funds, far surpassing others such as foreign exchange derivatives in size. Illustrating the magnitude of their swap positions, the second panel in Figure 1 shows the net notional of outstanding Euro-denominated interest rate swaps in 2020, split by different counterparties. As we can see from the figure, Dutch pension funds are net receivers of interest rate swaps with maturities above ten years. Their

[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 A3).

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.[8] 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.[9]

[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—combing 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 4 years.[10] Hence, Figure 2 suggests that pension funds adjust their portfolio duration using interest rate swaps and leaving their bond positions largely unchanged.

[8] Note that we only observe derivatives contracts in which at least one of the counterparties is established in the Netherlands. Hence, the net-notionals do not sum up to zero.

[9] 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 5 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 5 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 5 years to maturity held by Dutch pension funds was $694 billion in 2020.

[10] 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.

[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 A5 and Table A2).

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% 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.[11] For 74% of the pension funds in our sample, the realized margin calls are larger

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

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 A1).[12]

[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 decreases in long-dated swap rates to the funding status of DB pension plans. They argue that these drops in swap rates are driven by pension funds with worse funding status, who use more swaps. We can apply a similar argument in our context. Assume that the funding ratio of a pension fund deteriorates. If the pension fund wants to keep both its tactical asset allocation and its interest rate risk unchanged, it must increase its swap positions. We illustrate this point with a numerical example and through an illustrative model in Appendix B. Hence, our first hypothesis is that pension funds with a worse funding status use more interest rate swaps.

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

Hypothesis 1 links swap usage to pension funds' hedging demand. Yet, while swaps help protect pension funds from falling interest rates, increasing interest rates triggers margin

year.

[12]The reported margin calls are generally lower than our proxy as they exclude margins that are kept in an account and hence are not a threat to the liquidity exposures of pension funds.

calls. As discussed in Section 1, most margin calls require the pension fund to post cash collateral, and the amount of cash held by pension funds is substantially lower than the realized margin calls in our sample. Hence, to accommodate margin calls, it may be necessary for pension funds to liquidate parts of their portfolios. Drawing on previous studies highlighting investors respond to liquidity shocks by first selling their most liquid assets (e.g., Scholes, 2000; Ben-David et al., 2012; Manconi et al., 2012; Ma et al., 2022), our hypothesis is that pension funds follow a similar pattern, accommodating margin calls by selling their most liquid assets first. 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. Moreover, since safe government bonds typically benefit from lower transaction costs (e.g., Chordia et al., 2005) and smaller liquidity premiums (Meyer, Reinhart, and Trebesch, 2022), we expect pension funds to react to increasing swap rates by liquidating parts of their safe bond holdings.

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.

Hypothesis 2 allows us to directly test the effect of derivatives on asset allocations. As interest rates rise, bond prices fall. Consequently, a pension fund that is not subject to margin calls responds to rising interest rates by *increasing* its bond holdings in order to adhere to its 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.

To test the 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). In addition, these government bonds typically carry a convenience premium for being cash-like securities (e.g., Nagel, 2016).

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 government bonds.*

3 Empirical Evidence

In this section, we test our three hypotheses. First, we show that pension funds with tighter regulatory constraints, reflected in larger funding gaps, use more interest rate swaps. Second, we examine pension funds' fixed income portfolios and find that increasing swap rates correlate with net sales of fixed income securities. This link is driven by a pension fund's swap duration. More granular tests of the selling behavior in times of large interest rate hikes reveal that the selling is concentrated in safe and short-term Euro-denominated bonds. Finally, we examine how this selling pressure affects the prices of these securities.

3.1 Swap Usage and Regulatory Constraints

As a starting point for our analysis, Figure 4 shows a binned scatter plot of changes in portfolio durations on lagged funding gaps. If the lagged funding gap is negative, that is, if pension funds have a better funding ratio than required by regulators, the figure shows no correlation between the two variables. By contrast, pension funds with a positive funding gap tend to increase their portfolio duration as the funding gap widens. This is suggestive evidence in favor of Hypothesis 1.[13]

[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:

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

Guided by Figure 4, which suggests that 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 and the lagged logarithm of the funds' 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 after adding 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

[13] In the body of the paper, we focus our analysis on changes in swap durations rather than levels. This is a conservative approach; as illustrated in Figure A2, the association between the lagged funding gap and the level of the swap duration is even more pronounced. Moreover, while we focus on the swap duration in the body of the paper, Figure A4 of the Appendix illustrates the strong negative relation between the funding ratios and margin call risk over time.

of an underfunded pension fund increases its portfolio duration by 0.25 (= 1.632 × 0.1566) years.

[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 0.28 (= 1.797 × 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.

In Appendix Table A4 we show that these results are robust to a regression specification that includes the lagged funding gap without conditioning on whether a pension fund is underfunded. We also show that the results are robust to using the funding ratio instead of the funding gap in Table A5. Moreover, in Appendix Table A6, we address the endogeneity issue that arises when using contemporaneous changes in the funding gap by applying an IV methodology.

3.2 Response to Margin Calls from Swaps

We now use changes in swap rates to proxy for margin calls and first link these changes to pension funds' fixed income holdings. Afterwards, we study the selling behavior of specific fixed income securities in times of large interest rate hikes, which we interpret as realized liquidity risk because such rate hikes expose pension funds to margin calls.

3.2.1 Feedback from Interest Rate Swaps to Asset Allocation

Turning to the first part of Hypothesis 2, we now examine how maximum ten-day changes in swap rates affect the asset allocation of pension funds in our sample. 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. Formally, 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 $t-1$. The maximum ten-day change in the swap rate is computed as the maximum rolling change in the 20-year swap rate over a ten-day period (measured over business days).[14] $C_{i,t-1}$ are time-varying fund-level controls and include a fund i's lagged funding gap and duration gap. Importantly, to account for rebalancing effects in our analysis, we also control for the relative performance of a fund's equity compared to its fixed income portfolio in

[14] We show in the Appendix (Table A7) that our results remain virtually unchanged when using monthly changes instead of the maximum 10-day changes.

all our specifications. 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 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.

Columns (1) of Table 3 indicates a correlation between rising swap rates and the net selling of bond positions. Specifically, a one standard deviation increase in the swap rate change (0.13%) corresponds with a 0.10% decrease in fixed income holdings. This pattern is confirmed in Column (2), where 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. Consistent with larger margin calls during periods with notable spikes in swap rates, the economic impact is more pronounced: a one standard deviation increase in the swap rate change is associated with a 0.31% decrease in fixed income holdings. 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.

To further examine the impact of margin calls on bond sales, we 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 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, neither changes in the swap rate nor the lagged swap duration itself are statistically significant. This confirms that pension funds with larger swap durations are more exposed to margin calls as they sell more fixed income securities following increases in swap rates.

Finally, we add time fixed effects as an additional control to absorb any unobservable fluctuations in financial markets or the economy. In this specification, we drop changes in swap rates because they are absorbed by the time fixed effects. Hence, the focus in this specification is 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. The effects of rebalancing become insignificant as it is primarily influenced by stock and bond market returns, which are subsumed by the time fixed effect.

3.2.2 Selling Behavior During Interest Rate Hikes

Moving on to the second part of Hypothesis 2, we examine which bonds pension funds sell in response to margin calls. Our hypothesis is that they sell their most liquid securities first. Hence, 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 cash-like assets, such as 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 A7 of the Appendix confirms that pension funds sell their MMF shares during periods of substantial interest rate hikes (we define the eight event months in Table A2). This finding aligns with Ghio et al. (2023), who demonstrate that the 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).[15] 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

[15] As pointed out in a recent stress-test analysis 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.

and we therefore introduce an indicator variable $\mathbb{1}\{\text{AAA}_{j,t}\}$ that equals one if the issuer of security j has a triple-A rating from all three major rating agencies in period t and if security j is denominated in euro.[16] During our sample period, only Dutch and German government bonds held a triple-A rating from all three agencies. 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. We therefore also introduce an indicator variable $\mathbb{1}\{T \leq 7_{j,t}\}$ that equals one if the bond has a remaining time to maturity that is lower or equal to seven years.

To understand which parts of their fixed income portfolios pension funds liquidate when they face margin calls, we examine security-level changes in the notional amounts for each fund in each of the eight event months. 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 5, we observe larger declines in holdings for triple-A rated Euro-denominated bonds compared to other bonds.

[Insert Figure 5 near here]

We next run panel regressions of the following form:

$$\Delta\%Hold_{i,j,t} = \beta Dur^{Swap}_{i,t-1} \times \mathbb{1}\{\text{AAA}_{j,t}\} \times \mathbb{1}\{T \leq 7_{j,t}\} + \gamma C_{i,j,t} + \delta_j + \alpha_{i,t} + \varepsilon_{i,j,t}, \quad (4)$$

where $\Delta\%Hold_{i,j,t}$ captures the percentage change of fund $i's$ holding of security j, measured

[16]For pension funds that do not use central clearing, it is also common practice to place these bonds as collateral when variation margins rise. In that case, we would not observe that these assets leave the portfolio of the affected pension fund because bonds that are posted as collateral remain on the balance sheet of pension funds.

over each hike month t and $Dur^{Swap}_{i,t-1}$ is the duration of fund $i's$ swap portfolio in the previous quarter $t-1$. $C_{i,j,t}$ 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.[17] This specification allows us to test if pension funds with a higher exposure to margin calls sell more of their liquid assets.

Starting with a specification that only interacts the lagged swap duration with the triple-A indicator, Column (1) of Table 4 shows that sales of triple-A rated government bonds are more pronounced for funds with larger swap durations. Further examining this result, Column (2) shows that the regression coefficient remains virtually unchanged when adding time fixed effects. Similarly, Column (3) shows that adding both fund-time and security fixed effects leaves our inference unchanged. To show that the sales of triple-A bonds are concentrated at the short-end of the maturity spectrum, we also interact with $\mathbb{1}\{T \leq 7_{j,t}\}$ in Column 4-6. 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 short-term triple-A Euro-denominated bonds by -0.90%.

[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 aim to

[17] We cluster the standard errors in this regression at the fund level to allow for correlation in the error term across securities for a given fund. The reason is that the buying of certain securities usually comes with the selling of others (assuming no net cash inflows). The coefficient β remains statistically significant if we double cluster at the fund and security level or just at the security level (allowing the error term of pension funds trades in a given security to correlate with one another).

reduce the duration of their assets at the same time, they would sell long-term instead of short-term bonds.

3.2.3 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 6 near here]

Figure 6 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 the equity sales in 2022 are aligned with 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 accomodate margin calls. Hence, our findings represent a conservative estimate compared to a scenario where pension funds did not hold equities. Indeed, UK pension funds have significantly lower equity allocations than their Dutch counterparts,[18] which likely contributed to a more pronounced sell-off in the UK gilt market in 2022.

[18] 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).

3.3 Price Impact of Pension Funds

In this section, we first provide cross-sectional asset pricing regressions to show that bonds that are more likely to be sold as a result of margin call risk experience larger price drops during periods of interest rate hikes. We then show the aggregate effect of margin calls on Dutch government bond yields.

3.3.1 Cross-Sectional Bond Price Effects

Moving to Hypothesis 3, we note that Dutch pension funds are large investors in the safe Euro-denominated government bond market (Jansen, 2022), so the sales resulting from margin calls may have an adverse impact on bond prices. To that end, 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, 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. To that end, we first obtain issuance-level information for all German and Dutch government bonds from the respective auction schedules. We then obtain day-end clean mid-market prices from Thomson Reuters Eikon and compute returns during the ten-day period of maximum increases in swap rates for each bond in our sample.

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

[**Insert Figure 7 near here**]

We then move on to test the price impact more formally and run regressions of the following form:

$$r^b_{t+1} = \alpha + \beta MC^b_t + \gamma C^b_t + \varepsilon^b_{t+1}, \tag{6}$$

where r^b_{t+1} is the ten-day percentage change in the clean price of bond b, MC^b_t is our margin call risk measure for bond b, and C^b_t includes an indicator variable that equals one if bond j is issued by the Netherlands, the time-to-maturity, time since issuance (age), coupon rates, and log total outstanding volume for bond b.

Column (1) and (2) of Table 5 show the results combining German and Dutch government bonds of all maturities. The relationship between our margin call risk measure and returns is insignificant. However, zooming in on bonds with remaining time to maturities of seven years or lower, we find that the ten-day returns of bonds exposed to pension funds with more margin call risk are significantly lower. As shown in Columns (4), this result remains virtually unchanged when we control for year-to-maturity fixed effects. In terms of economic magnitude, a one standard deviation 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 interest rate hikes.

Interestingly, separating German and Dutch debt, Columns (5) and (6) reveal that the economic significance of our margin call proxy is more than 1.5 times stronger for Dutch bonds. This finding is in line with the fact that Dutch debt has a lower market liquidity compared to German debt. Hence, selling pressure by Dutch pension funds is likely to have a stronger impact on these bonds.

[Insert Table 5 near here]

3.3.2 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 Dutch government bonds to sales by pension funds, using the Granular Instrumental Variables (GIV) approach developed by Gabaix and Koijen (2020). To obtain granular bond holdings, we expand our monthly data of Dutch pension funds to January 2009 and also include Dutch insurance companies, mutual funds, and banks at the institution level in the sample.[19] This expanded sample captures 206 institutions that hold, on average, 26% of all Dutch debt outstanding.

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 ($\Delta q_{i,t}$). To extract idiosyncratic shocks to these holdings, we run weighted regressions of the following form:[20]

$$\Delta q_{i,t} = \alpha_t + \alpha_i + \beta_{0,i} GDPgrowth_t + \beta_{1,i} \Delta Inflation_t + \beta_{2,i} \Delta Fiscal_t + \beta_{3,i} t + \Delta \check{q}_{i,t}. \quad (7)$$

[19]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.

[20]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.

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, and a time trend as controls with coefficient loadings that can vary across investors.[21] Because our holding 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. From regression (7) we obtain the idiosyncratic demand shocks $\check{q}_{i,t}$. 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.

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:

$$\begin{aligned} \Delta Yield_t &= MZ_t + \gamma_0 GDPgrowth_t + \gamma_1 \Delta Inflation_t + \gamma_2 \Delta Fiscal_t \\ &+ \lambda_1 PC_{1,t} + \lambda_2 PC_{2,t} + \lambda_3 PC_{3,t} + \alpha + \varepsilon_t. \end{aligned} \tag{8}$$

In the regressions, we use the 5-year Dutch government bond yield. 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 control for any common comovements in holdings that may affect yields.

Table 6 shows the results. Column (1) shows the results when we look at the weighted sum of actual changes in holdings, rather than the residual changes. Because of confounding

[21] Fiscal capacity is defined as the net amount lend minus borrowed, relative to GDP.

factors, we do not detect a statistically significant link between changes in holdings and bond yields. However, Columns (2)-(6) show that the GIV instrument is able to uncover the impact of demand on bond yields. Across specifications we find that a 1% inflow into the Dutch debt market reduces the 5-year yield by 3.4 basis points. This result remains virtually unchanged when controlling for two or three of the principal components. As a final step, we link our GIV estimates to the price pressure resulting from margin calls. For instance, during the COVID-19 pandemic, pension funds sold €4.19 billion of their total Dutch government bond portfolio, which translates into 1.3% of the total debt outstanding. Hence, this selling because of margin calls increased the Dutch 5-year yield by 4.5 basis points, or 10% of the ten-day increase in the 5-year yield during that period.

[**Insert Table 6 near here**]

4 Conclusion

This paper highlights that pension funds use interest rate swaps to hedge the interest rate risk of their liabilities. Our rich dataset then allows us to quantify the potential liquidity risk from margin calls that arises from swap usage. We show that realized margin calls range from 4.5% to 15% of pension funds' total AUM.

Furthermore, our analysis uncovers 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 we show that 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 has the unintended consequence of introducing funding 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.

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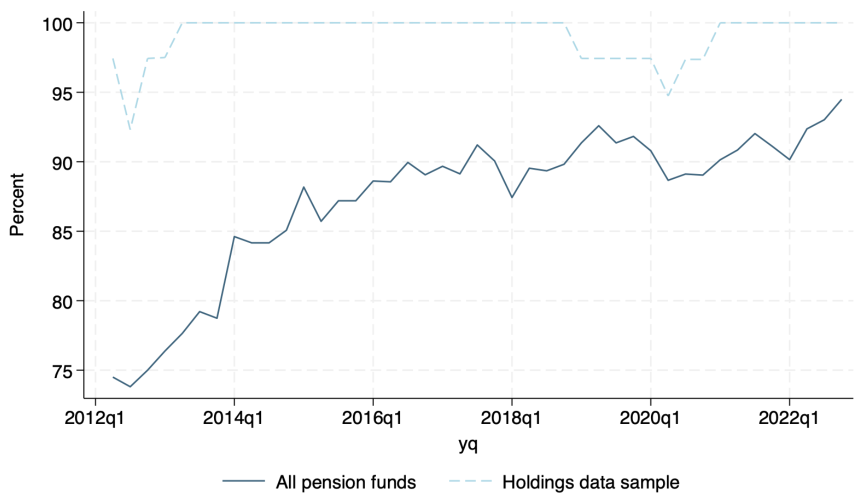
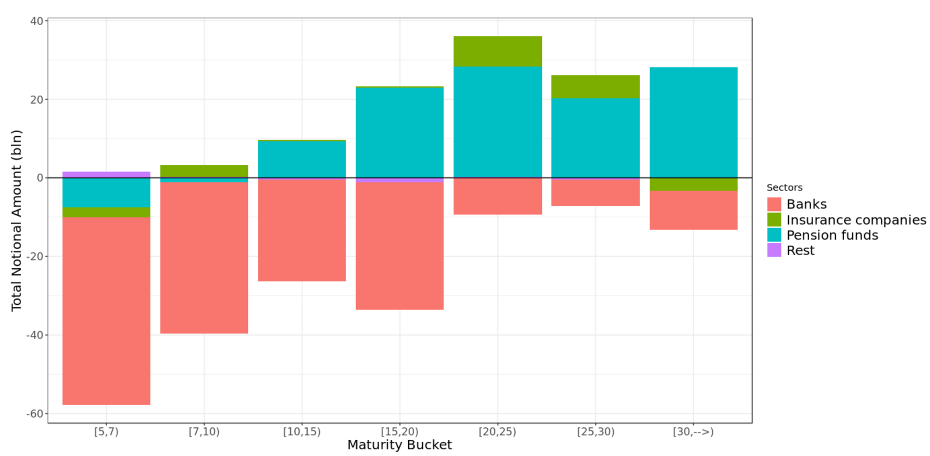
Figures and Tables

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.

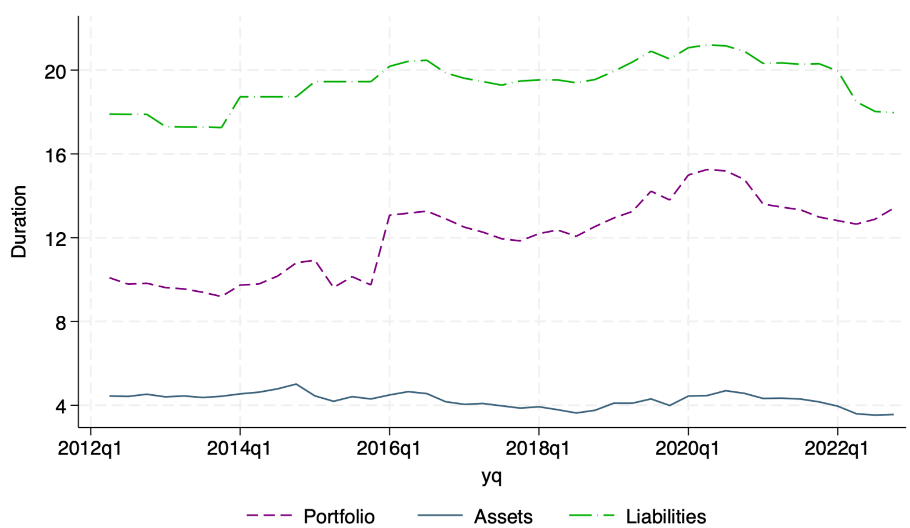
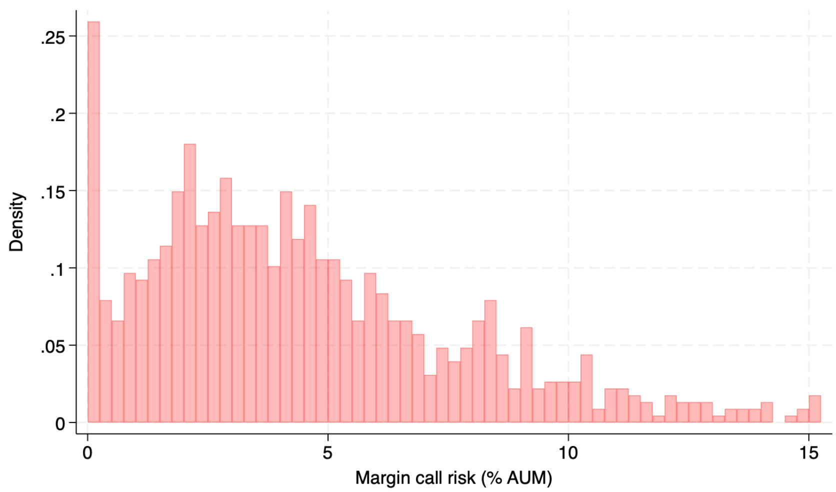
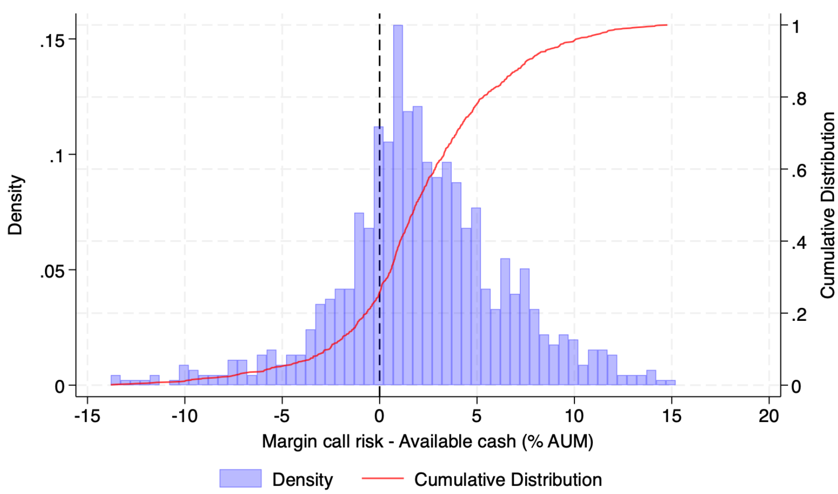


Figure 3: **Margin call risk versus available cash**

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.

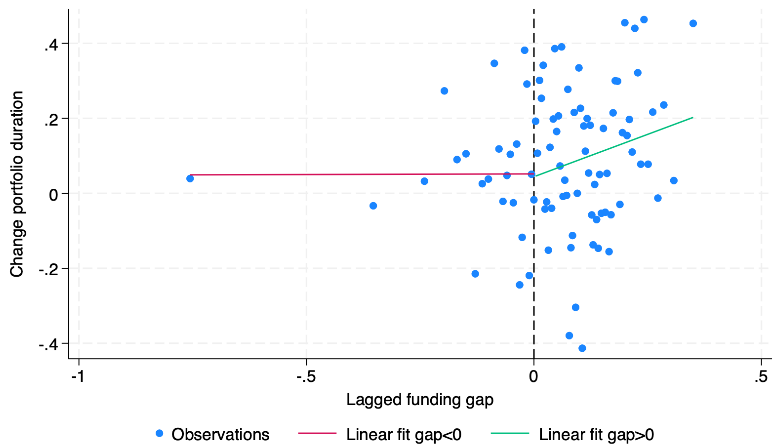


Figure 5: **Changes in bond holdings during periods of interest rate hikes**

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).

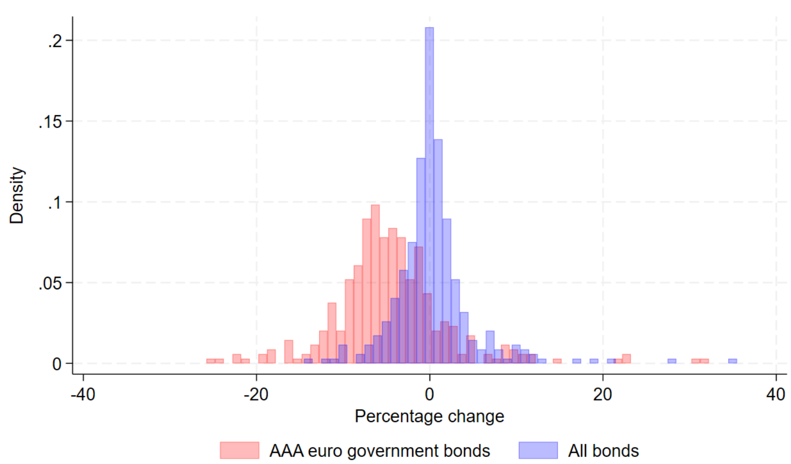
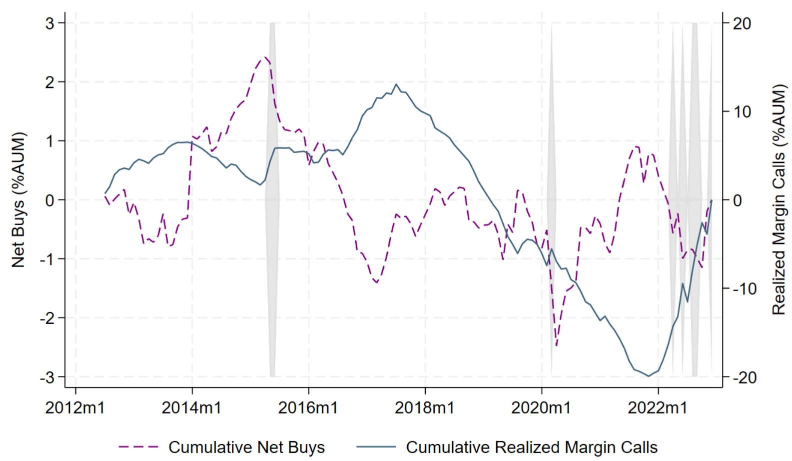
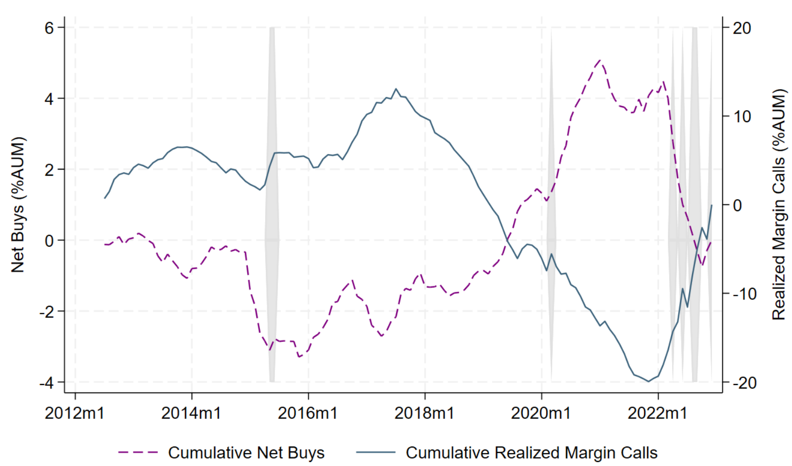


Figure 6: **Cumulative fixed income versus equity sales**

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 7: **Margin call risk exposure and bond returns**

This graph plots our measure of margin call risk 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 7 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.

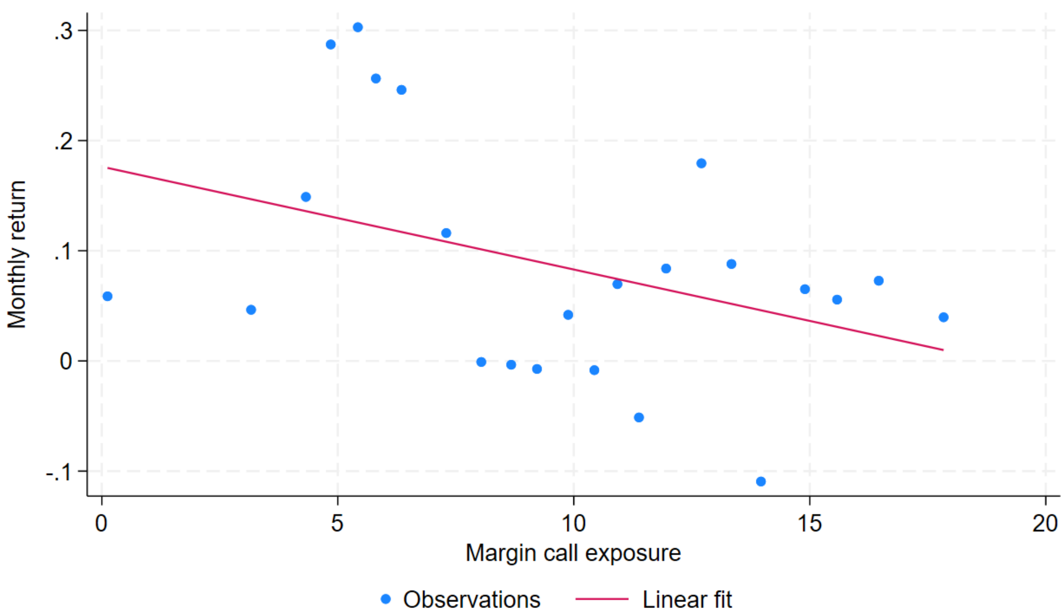


Table 1: **Summary statistics**: Panel A shows summary statistics on the AUM (billions), funding ratio, required funding ratio (pp), funding ratio gap (pp), allocation to fixed income (pp), allocation to cash (pp), allocation to equities (pp), duration of the liabilities (years), duration of the assets (years), and the duration of the swaps (years). Cash includes money market funds and (term) deposits with time to maturities of less than one year. Panel B reports summary statistics on the bond holdings data to geographies and bond types (pp). DE indicates Germany and NL the Netherlands. 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)	6.68	33.68	0.06	0.76	24.06	8018
Funding ratio	110.70	15.89	92.38	108.70	134.40	8018
Funding ratio gap	6.26	15.66	-17.20	7.79	26.17	8018
Allocation fixed income	55.29	19.04	19.83	56.29	88.22	8018
Allocation cash	2.60	4.42	-0.30	1.41	9.58	6937
Allocation equity	33.40	11.98	16.26	32.12	53.87	7996
Duration liabilities	19.23	3.81	13.69	18.90	25.80	8018
Duration portfolio	11.72	5.58	3.47	11.03	21.88	8017
	Panel B: Monthly Bond Holdings Data					
	mean	sd	p5	p50	p95	N
% in the Euro area	70.04	18.52	35.91	70.77	100.00	5490
% in corporate bonds	34.07	20.78	0.00	34.06	69.09	5490
% in government debt	65.93	20.78	30.91	65.94	100.00	5490
% of gov debt in DE	31.67	18.55	5.51	29.34	66.66	5483
% of gov debt in NL	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, 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 and AUM. 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} $(t-1)$	0.813***	1.632***	0.883**	1.797**	-0.202	-0.513*
	[0.242]	[0.496]	[0.355]	[0.833]	[0.170]	[0.305]
Funding gap $(t-1)$	0.06	0.303	0.007	0.079	-0.051	0.145
	[0.116]	[0.230]	[0.284]	[0.794]	[0.056]	[0.127]
D^{UF} $(t-1)$	-0.051	-0.018	-0.057	0.01	0.052*	0.039
	[0.053]	[0.070]	[0.064]	[0.086]	[0.031]	[0.035]
Liability duration $(t-1)$	0.008**	0.015	0.006	0.03	0.004	-0.01
	[0.004]	[0.027]	[0.004]	[0.036]	[0.002]	[0.011]
ln AUM $(t-1)$	-0.007	-0.457**	-0.01	-0.339	0.015***	-0.062
	[0.007]	[0.193]	[0.008]	[0.217]	[0.004]	[0.102]
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	7758	7758	6615	6612	7758	7758
Adj. R-squared	0.165	0.152	0.171	0.156	0.075	0.072

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, and duration gap. 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	-0.817***		0.589			
	[0.259]		[0.437]			
$\mathbb{1}\{\text{High}\}$		-0.301**			0.207	
		[0.123]			[0.214]	
$Dur^S\ (t-1) \times \Delta r^S$			-0.189***	-0.184***		
			[0.051]	[0.052]		
$Dur^S\ (t-1) \times \mathbb{1}\{\text{High}\}$					-0.069***	-0.074***
					[0.024]	[0.024]
$Dur^S\ (t-1)$			-0.032	0.031	-0.052***	0.013
			[0.021]	[0.025]	[0.020]	[0.024]
Relative equity return (t)	-3.477	-4.495	-3.219	-9.022	-4.057	-9.715
	[4.113]	[4.136]	[4.236]	[18.647]	[4.243]	[18.709]
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 ($t-1$)	-0.13	-0.161	-0.348	0.736	-0.429	0.807
	[0.189]	[0.189]	[0.459]	[0.787]	[0.476]	[0.787]
Duration gap ($t-1$)	-0.006	-0.006	-0.052**	0.011	-0.048**	0.014
	[0.007]	[0.007]	[0.021]	[0.025]	[0.021]	[0.025]
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	0.00	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 a 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 below 7 years. Time, security, and fund-time fixed effects are included as indicated. Standard errors are clustered at the fund level and reported in brackets. Significance: ***99%, **95%, *90%.

	Δ Nominal bond holdings					
	(1)	(2)	(3)	(4)	(5)	(6)
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA}\}$	-0.090***	-0.080***	-0.081**	-0.048	-0.037	-0.011
	[0.029]	[0.029]	[0.035]	[0.033]	[0.033]	[0.038]
$Dur^S(t-1) \times \mathbb{1}\{\text{AAA}\} \times \mathbb{1}\{T \leq 7\}$				-0.091***	-0.093***	-0.158***
				[0.029]	[0.029]	[0.054]
$Dur^S(t-1) \times \mathbb{1}\{T \leq 7\}$				-0.001	-0.003	0.029***
				[0.009]	[0.009]	[0.010]
$Dur^S(t-1)$	0.011**	0.002		0.011	0.003	
	[0.005]	[0.005]		[0.007]	[0.007]	
$\mathbb{1}\{\text{AAA}\}$	0.429	0.367		0.336	0.285	
	[0.296]	[0.298]		[0.297]	[0.299]	
$\mathbb{1}\{T \leq 7\}$				-0.133	-0.076	
				[0.104]	[0.103]	
Time FE	No	Yes	No	No	Yes	No
Security FE	No	No	Yes	No	No	Yes
Fund-Time FE	No	No	Yes	No	No	Yes
Obs.	398,157	398,157	393,799	398,157	398,157	393,799
R-squared	0.00	0.02	0.15	0	0.02	0.15

Table 5: **Price impact of margin call risk**: We perform regressions of bond returns during the 10-day period of maximum swap rate changes on the lagged measure of margin call risk during periods of interest rate hikes: 2015M5, 2015M6, 2020M3, 2022M4, 2022M6, 2022M8, 2022M9, and 2022M12. Controls include time-to-maturity (TTM), time since issuance (Age), coupon rates (Coupon), log total amount outstanding (log(Outst)), and an indicator whether the bond is issued by the Netherlands ($\mathbb{1}\{\text{Dutch}\}$). We show the results for all bonds (Column 1-2) and for bonds with remaining time-to-maturity below 7 years (Column 3-6). We also show the results separately for German (Column 5) and Dutch debt (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%.

	$r_t^{b,max}$					
	DE and NL debt				**DE debt**	**NL debt**
	All Maturities		$T \leq 7$			
	(1)	(2)	(3)	(4)	(5)	(6)
MC risk ($t-1$)	0.011	0.008	-0.010***	-0.013***	-0.010***	-0.017***
	[0.007]	[0.005]	[0.003]	[0.003]	[0.004]	[0.005]
TTM	-0.270***		-0.247***			
	[0.006]		[0.007]			
Age	0.029**	0.017*	-0.014***	-0.013***	-0.022***	-0.008**
	[0.012]	[0.009]	[0.005]	[0.004]	[0.004]	[0.004]
Coupon	-0.110***	-0.074**	0.043**	0.037**	0.075***	0.011
	[0.041]	[0.033]	[0.019]	[0.016]	[0.017]	[0.014]
log(Outst)	0.137**	0.089*	-0.013	-0.042***	-0.036**	-0.019
	[0.056]	[0.045]	[0.015]	[0.012]	[0.016]	[0.023]
$\mathbb{1}\{\text{Dutch}\}$	0.140*	0.170**	-0.003	-0.004		
	[0.078]	[0.076]	[0.023]	[0.023]		
Year-to-maturity FE	No	Yes	No	Yes	Yes	Yes
Obs.	767	767	491	491	346	145
R-squared	0.81	0.83	0.54	0.54	0.54	0.55

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 5-year bond yield of Dutch government debt. 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 and the first three principal components of the residuals in Equation (7). The data are monthly from February 2009 to December 2022. Newey-West standard errors are reported in brackets. Significance: ***99%, **95%, *90%.

	Dutch 5-year yield					
	(1)	(2)	(3)	(4)	(5)	(6)
Q	-3.907					
	[2.675]					
Z		-2.391*	-3.395**	-3.395**	-3.417**	-3.404**
		[1.265]	[1.594]	[1.598]	[1.577]	[1.617]
GDP growth			2.037**	2.037**	2.037**	2.037**
			[0.791]	[0.794]	[0.803]	[0.807]
Fiscal (% change)			2.804	2.803	2.817	2.809
			[2.651]	[2.659]	[2.626]	[2.662]
Inflation (% change)			0.772***	0.772***	0.772***	0.772***
			[0.079]	[0.079]	[0.077]	[0.077]
PC1				2.037**	0.069	0.069
				[0.803]	[0.462]	[0.460]
PC2				2.817	-0.542	-0.542
				[2.626]	[0.553]	[0.554]
PC3						0.061
						[1.315]
Obs.	164	164	164	164	164	164
R-squared	0.02	0.01	0.07	0.07	0.07	0.07

Appendix

A Additional Details on Pension Regulation

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

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

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

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

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

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

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

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 A1 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.

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 A1 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 $PV(L) = LP$.[22] 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 $F = A - LP$.[23] 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 the Internet Appendix. Proposition 1 implies that pension funds use more swaps when they face tighter constraints in the form of lower funding ratios.

[22]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.

[23]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.

Table A1: **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

C 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:

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

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 between these two measures.

In this appendix, we present additional descriptive statistics and results that were omitted in the body of the paper. Section D contains additional descriptive statistics. Section E contains additional empirical tests. Section B.2 presents a simple theory linking pension funds' funding ratios and their demand for swaps.

D Additional Descriptive Statistics

Figure A1 illustrates the correlation between our proxy for margin call risk and the factual margin calls reported by 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 shows a time-series of the daily level and changes of the 20-year swap rate over time.

[Insert Figure A5 near here]

Table A2 list all months during our sample period when we observe an increase in the 20-year swap rate exceeding 40 basis points.

[Insert Table A2 near here]

E Additional Empirical Results

Table A3 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 A3 near here]

Table A4 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 A4 near here]

Finally, Table A5 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 A5 near here]

E.1 Robustness to Alternative Specifications

So far, 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 returns of the MSCI world index as an instrument for changes in the funding gap. More specifically, we run regressions of the following form:

$$\Delta Dur_{i,t} = \beta \widehat{FGap}_{i,t} + \Delta C_{i,t} + \varepsilon_{i,t}, \tag{A.3}$$

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.

Table A6 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 A6 near here]

Table A7 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 A7 near here]

Figure A1: **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 $\Delta r = +1\%$.

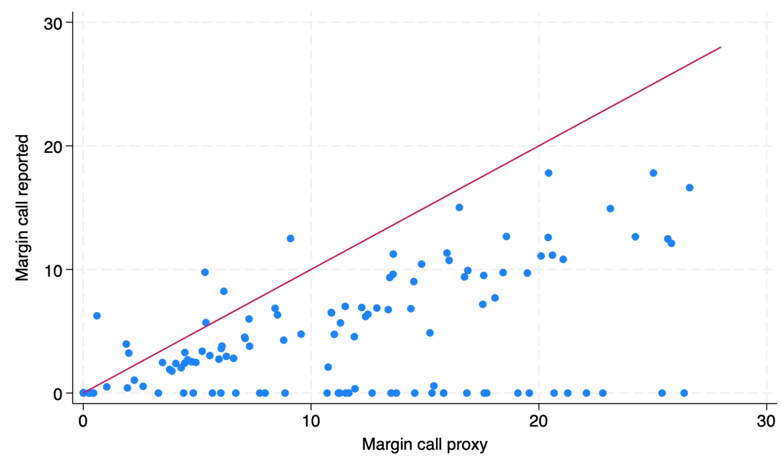


Figure A2: **Exposure to margin call risk and the funding gap**

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.

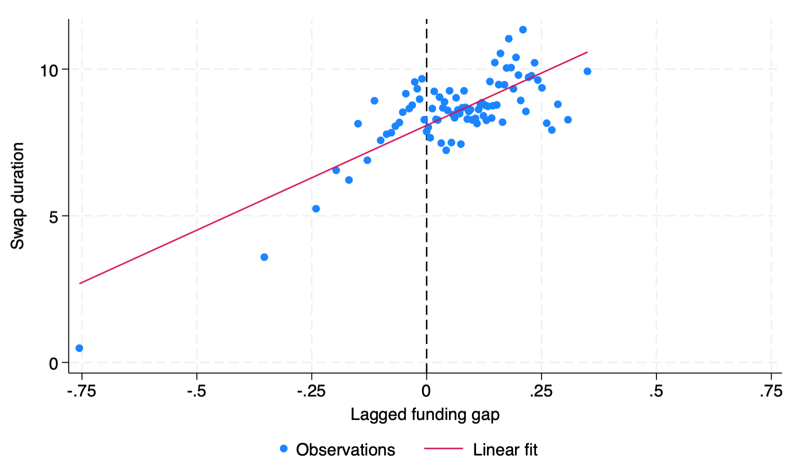


Figure A3: **Actual versus counterfactual funding ratios**

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.

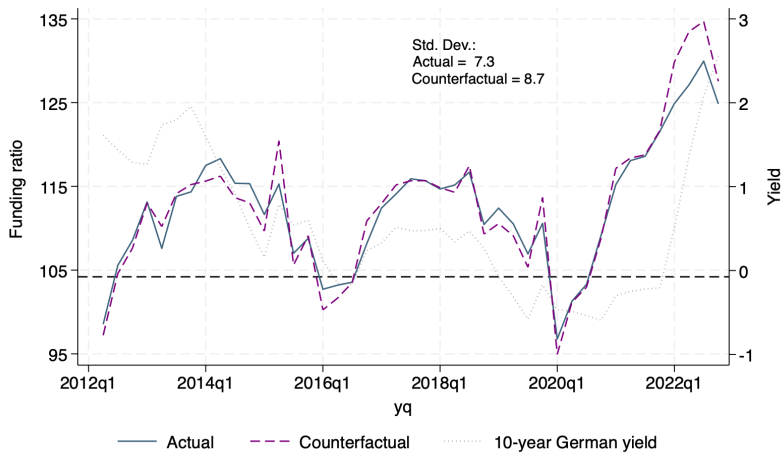


Figure A4: **Funding ratios and margin calls**

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.

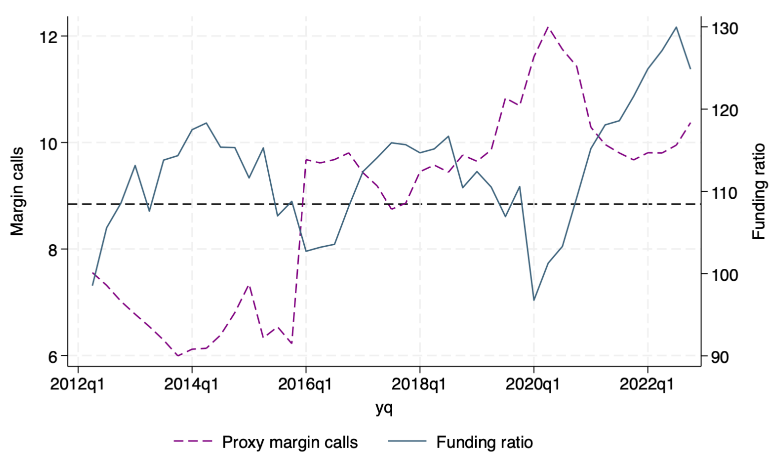


Figure A5: **Swap rates**

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.

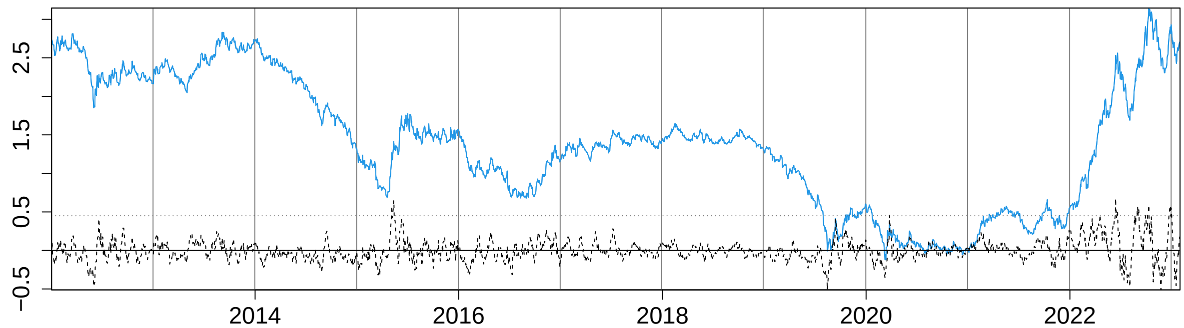


Figure A6: **Usage of interest rate swaps versus other derivatives.** This figure shows the mark-to-market value of interest rate swaps and other derivatives held by Dutch pension funds. These fluctuations show that interest rate swaps are by far the most important derivatives used by Dutch pension funds. Source: DNB public statistics.

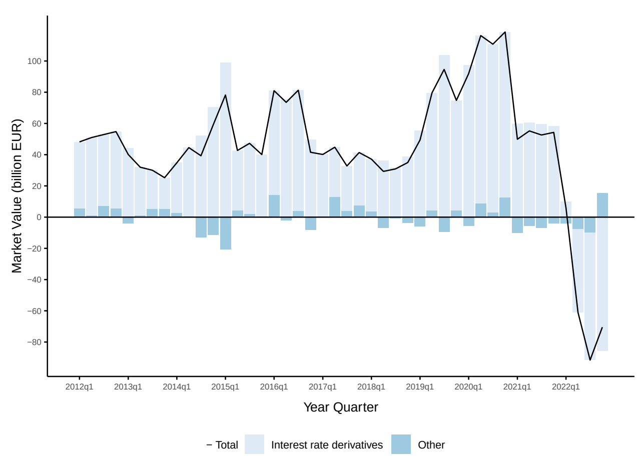


Figure A7: **Cumulative money market fund sales**

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.

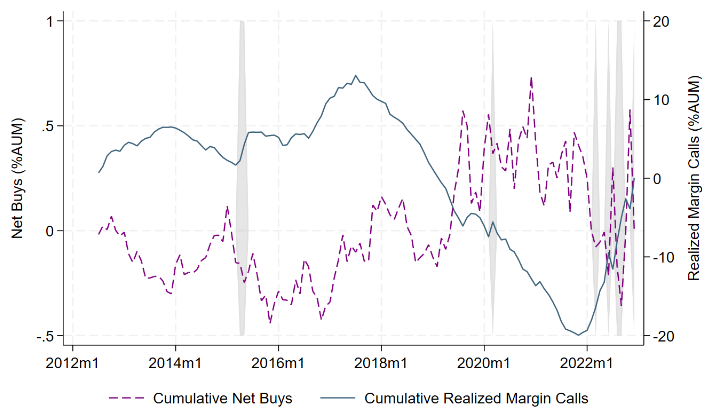


Table A2: **Large swap rate increases during our sample period.** This table shows the months in which we observe 10-day changes in the 20-year swap rate that exceed 40 basis points.

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 A3: **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, and AUM. We report the results for a linear probability model (Column 1) and a logit model (Column 2). Significance: ***99%, **95%, *90%.

	Linear prob	**Logit**
	(1)	(2)
Funding gap	0	-0.006
	[0.002]	[0.010]
Liability duration	-0.027***	-0.099***
	[0.005]	[0.038]
ln AUM	-0.055***	-0.288***
	[0.010]	[0.074]
Obs.	258	258
Adj. R-squared	0.178	

Table A4: **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 and AUM. 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 $(t-1)$	0.288***	0.780***	0.362***	1.214**	0.005	0.044
	[0.093]	[0.271]	[0.133]	[0.488]	[0.041]	[0.094]
Liability duration $(t-1)$	0.009**	0.023	0.007*	0.031	0	-0.007
	[0.004]	[0.027]	[0.004]	[0.037]	[0.002]	[0.012]
ln AUM $(t-1)$	-0.006	-0.459**	-0.007	-0.36	0.007**	-0.029
	[0.007]	[0.195]	[0.008]	[0.224]	[0.003]	[0.065]
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	7758	7758	6615	6612	7758	7758
Adj. R-squared	0.165	0.151	0.171	0.156	0.065	0.051

Table A5: **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 and AUM. 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 $(t-1)$	-0.194**	-0.580***	-0.285**	-0.950**	0.01	-0.105
	[0.083]	[0.216]	[0.142]	[0.453]	[0.039]	[0.078]
Liability duration $(t-1)$	0.011***	0.025	0.009**	0.035	0	-0.007
	[0.004]	[0.027]	[0.004]	[0.036]	[0.002]	[0.012]
ln AUM $(t-1)$	-0.004	-0.436**	-0.005	-0.318	0.007**	-0.032
	[0.007]	[0.196]	[0.008]	[0.225]	[0.003]	[0.065]
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	7758	7758	6615	6612	7758	7758
Adj. R-squared	0.165	0.151	0.17	0.156	0.065	0.051

Table A6: **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	8.029***	9.575***	7.090***	8.996***	2.064***	2.030***
	[1.240]	[1.314]	[1.479]	[1.873]	[0.572]	[0.568]
Δ Liability duration	0.084*	0.047	0.089	0.047	-0.011	-0.012
	[0.050]	[0.048]	[0.055]	[0.053]	[0.020]	[0.020]
Δ ln AUM	0.513	0.365	-0.151	0.212	0.451	0.473
	[0.533]	[0.478]	[0.593]	[1.071]	[0.360]	[0.369]
Δ 10-year German yield	-0.774***	-0.771***	-0.647***	-0.609***	-0.217***	-0.216***
	[0.118]	[0.114]	[0.131]	[0.179]	[0.059]	[0.061]
Fund FE	No	Yes	No	Yes	No	Yes
Obs.	7542	7542	6410	6407	7542	7542
Adj. R-squared	0.043	0.034	0.035	0.028	0.018	0.018
First stage:						
Coefficient	-0.009	-0.009	-0.009	-0.009	-0.009	-0.009
t-stat first stage	-26.48	-26.43	-26.23	-26.19	-26.6	-26.51

Table A7: **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, and duration gap. 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	-0.538***		0.367			
	[0.179]		[0.293]			
$\mathbb{1}\{\text{High}\}$		-0.301**			0.207	
		[0.123]			[0.214]	
$Dur^S\ (t-1) \times \Delta r^S$			-0.120***	-0.116***		
			[0.035]	[0.036]		
$Dur^S\ (t-1) \times \mathbb{1}\{\text{High}\}$					-0.069***	-0.074***
					[0.024]	[0.024]
$Dur^S\ (t-1)$			-0.059***	0.005	-0.052***	0.013
			[0.020]	[0.024]	[0.020]	[0.024]
Relative equity return (t)	-1.472	-4.495	-1.546	-7.564	-4.057	-9.715
	[4.187]	[4.136]	[4.303]	[18.649]	[4.243]	[18.709]
Relative equity return ($t-1$)	8.293**	6.886*	8.659**	23.676	6.313*	20.977
	[4.023]	[3.957]	[4.059]	[19.427]	[3.993]	[19.529]
Funding gap ($t-1$)	-0.101	-0.161	-0.186	0.699	-0.429	0.807
	[0.190]	[0.189]	[0.459]	[0.790]	[0.476]	[0.787]
Duration gap ($t-1$)	-0.007	-0.006	-0.052**	0.011	-0.048**	0.014
	[0.007]	[0.007]	[0.021]	[0.025]	[0.021]	[0.025]
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	0.00	0.00	0.02	0.05	0.02	0.05

Internet Appendix

Not for publication

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

Proofs

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

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

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

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

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

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

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

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

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

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

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

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

which gives:

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

Plugging this into a and b gives:

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

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 (A.5) holds.

Swap Demand

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

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

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

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

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

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

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

■

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