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Abstract

This paper empirically assesses the impact of liquidity and capital requirements on the strategic allocation of defined benefit pension funds to illiquid asset classes using unique and unbiased data. Liquidity requirements result from short-term pension payments and margin calls on derivative positions, while capital requirements are enforced by the regulator to absorb unexpected losses. The liability duration and interest rate/currency risk hedging both affect the allocation to illiquid assets through these requirements. Consistent with our theoretical framework, we document how these liquidity and capital requirements affect the allocation to illiquid assets. For instance, pension funds with low liability duration have high liquidity requirements resulting in low illiquid assets allocations. On the other hand, pension fund with high liability duration have low liquidity requirements, but high capital requirements as a result of interest rate risk, limiting opportunities to invest in illiquid assets.

Keywords: Illiquid assets, asset liability management, asset allocation, liquidity requirements, capital requirements, pension funds.
JEL classifications: G11, G23.

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1 Introduction

Pension funds are important investors in illiquid assets such as real estate, mortgages, private equity, hedge funds, and infrastructure. The latest annual OECD survey of large pension funds and public pension reserve funds reveals an average illiquid assets allocation of 15 percent in 34 countries.[1] According to the 2018 Willis Towers Watson Global Pension Asset Study the 7 largest pension markets in the world (Australia, Canada, Japan, the Netherlands, Switzerland, UK, and US) have increased their average illiquid assets allocation from 4 percent in 1997 to 25 percent in 2017.[2] Illiquid assets may offer pension plans benefits in terms of a liquidity premium e.g., Sadka (2010), Franzoni et al. (2012), and Qian and Liu (2012), liability hedging (Hoevenaars et al., 2008), and portfolio diversification (Jacobs et al., 2014). The long investment horizon make pension funds well suited investors in illiquid assets classes (Attig et al., 2012).

Several papers study the risk-taking investment behavior of pension funds, e.g. Sharpe (1976), Jin et al. (2006), Rauh (2009), An et al. (2013), and Andonov et al. (2017). The focus in these papers is typically on the allocation to safe assets (such as government bonds) on the one hand versus risky assets (such as equities) on the other hand. In this paper we address the investment policy of pension funds regarding illiquid asset classes. How can we link pension funds' characteristics to their investments in illiquid assets? In particular, how do liquidity and capital requirements influence the illiquid assets allocation? We build our paper on a theoretical model of liquidity and capital requirements. To the best of our knowledge, we are the first to study the impact of these requirements on investment decisions in illiquid assets.

First, we assess the aggregate illiquid assets allocation, following the typical top-down decision making process of pension funds. Second, we study the implications for separate illiquid asset classes. While the empirical analysis is based on defined benefit pension plans in this paper, our theoretical framework also applies to different type of institutional investors. For instance, insurers are subject to liabilities and need to take into account both liquidity and capital requirements in choosing the optimal allocation to illiquid assets. Also banks are exposed to liquidity and capital requirements in their asset allocation decision (Khan et al., 2017).

[1] www.oecd.org/daf/fin/private-pensions/2015-Large-Pension-Funds-Survey.pdf
[2] https://www.willistowerswatson.com/-/.../Global-Pension-Asset-Study-2018-Japan.pdf

The main purpose of this paper is to show how both liquidity and capital requirements affect the appetite of, in our case, pension funds towards illiquid assets. We use the term *liquidity requirements* to denote the required liquidity (e.g., cash) of a pension fund for its immediate liquidity needs. These consist, in turn, of two components: short-term pension payments and collateral requirements (possible margin calls) on derivative positions. The cash required for pension payments is generally well predictable. However, the cash needed for collateral requirements is much less predictable. If the market value of a derivative declines, the pension fund is required to transfer cash or highly liquid short-term bonds to a margin account in order to limit the risk the counter party faces. Margining on derivatives can become quite substantial, especially during financial crises.

We also consider *capital requirements* as a source of variation in illiquid asset holdings by pension funds. Regulation often requires defined benefit plans to have sufficient capital to manage the risks they are exposed to, such as interest rate risk, market risk, currency risk, and longevity risk. In choosing the strategic asset allocation, a pension fund optimizes the trade-offs between different risk factors for a given level of required capital. As a result, pension funds are constrained to increase their exposure to illiquid assets given a certain level of available capital. For instance, a longer liability duration increases a pension fund's interest rate risk exposure. Given a certain level of available capital, this, in turn, decreases the opportunities to invest in illiquid assets. Several papers provide evidence that regulation has a significant impact on pension fund's investment decisions, e.g., Sias (2004), An et al. (2013), and Andonov et al. (2017).

Liquidity and capital requirements interact. Take, e.g., liability duration as a measure of a pension fund's average investment horizon. On the one hand, a pension fund with a high liability duration is less liquidity constrained as it will have to pay less pensions in the short-term. This allows for a higher allocation to illiquid assets. On the other hand, a high liability duration implies that the pension fund is more exposed to interest rate risk through the present value of its liabilities. This might restrict the opportunity to invest in illiquid assets as more of the available capital serves to manage interest rate risk. Another example of interaction between liquidity and capital requirements reveals if we look at derivatives. For instance, hedging interest rate risk increases the liquidity requirement as a result of higher collateral requirements. However, by hedging interest rate risk, the pension fund is less exposed to this risk factor and might take additional risk elsewhere before the capital requirement is binding. Hedging therefore creates opportunities to invest more in illiquid assets. Our theoretical model in Section 2 precisely disentangles these effects.

We empirically test the predictions from our theoretical framework of liquidity and capital requirements affecting the illiquid assets allocation. We analyze the investment decisions of Dutch occupational pension funds in our paper, which have mandatory reporting requirements to the prudential supervisor, De Nederlandsche Bank (DNB). The Dutch pension system is a useful setting for such an analysis for several reasons. First, the Dutch pension system is large in terms of size. The total assets under management (AUM) of Dutch pension funds' equals approximately 1.3 trillion euro. This reflects roughly 1.5 times the GDP of the Netherlands. Second, Dutch pension funds do not face investment restrictions. Regulation allows them to invest in any asset class in any country, as long as a pension fund understands the risks of the asset class and is compliant with the capital requirement. As a result, Dutch pension funds invest in a broad range of asset classes, including many illiquid ones. In fact, over two-thirds of Dutch pension funds invest in illiquid assets. Third, Dutch pension funds mainly have defined benefit pension liabilities. This means that they have a clear asset-liability perspective in deriving the strategic asset allocation. The defined benefit liabilities are valued marked-to-market by discounting accrued benefits against the prevailing term structure of interest rates. As a result, we can analyze the impact of interest rate risk on the illiquid assets allocation. These unique data are, thus, particularly well suited to study the effect of pension fund's liquidity and capital requirements on the illiquid assets allocation.

1.1 Preview of main results

We use two key pension fund characteristics that impact both liquidity and capital requirements: liability duration and collateral requirements on derivatives. We analyze how these requirements affect the fraction of risky assets allocated to illiquid assets. In short we offer the following contributions. First, in line with a theoretical framework, we find a hump-shaped impact of liability duration on the fraction of risky assets invested in illiquid assets (Figure 2). Up to 18 years, liability duration positively affects this allocation. A one year increase in the liability duration from 10 to 11 years, e.g., implies an increase in the fraction of risky assets invested in illiquid assets of 1.07 percentage points (Table 7). Up to the point of reversal the marginal benefit of a lower liquidity requirement outweighs the marginal costs of an increase in the capital requirement. However, beyond this point, the effect is reversed. The fraction of risky assets allocated to illiquid assets decreases. The marginal costs of an increase in the capital requirement now dominates the marginal benefits of a decrease in the liquidity requirement. A one year increase in the liability duration from 25 to 26 years implies a decrease in the fraction of risky assets allocated to illiquid assets of 1.02 percentage points (Table 7). These results are also supported by analyzing the illiquid asset classes separately.

Second, we do not find evidence that interest rate risk hedging impacts the fraction of risky assets allocated to illiquid assets. This indicates that neither the liquidity nor the capital requirement of hedging interest rate risk dominates, as our simplified theoretical framework would predict. In case of currency risk, however, hedging does impact the fraction of risky assets allocated to illiquid assets positively. In line with the positive (less capital requirements) and negative (more liquidity needs) implications of hedging, currency risk hedging creates the opportunity for pension funds to take additional risks by investing in illiquid assets. At first glance, this result seems to conflict the predictions of our model. However, in practice liquidity requirements for currency derivatives are generally less strict than for interest rate derivatives. Relating this to our theoretical framework, this implies the increase in the liquidity requirement is smaller than the decrease in the capital requirement, creating opportunities to invest in illiquid assets. A one standard deviation increase in hedging currency risk leads to an increase in the fraction of risky assets allocated to illiquid assets of approximately 0.71 percentage points (Table 7). This implies a relative increase in the fraction of risky assets allocated to illiquid assets of 5.5 percent. These findings are not in all cases supported by analyzing illiquid asset classes separately. These results indicate that strategic decisions made at the top level do not have to be implemented at each individual asset class level. What matters is that the overall investment policy, risk exposures and liquidity profile are in accordance with the policy set by the board of trustees.

Finally, we find that also other pension fund characteristics impact strategic asset allocation decisions. Size positively affects the fraction of risky assets allocated to illiquid assets, which is in line with previous literature, Andonov (2014) and

Dyck and Pomorski (2016). A pension fund that is ten times larger in terms of assets under management has a 7.4 percentage points higher fraction of risky assets allocated to illiquid assets (Table 7). Furthermore, corporate pension funds tend to invest 7.6 percentage points less in illiquid assets as fraction of risky assets compared to industry-wide and professional group pension funds (Table 7). Corporate pension funds generally take less mismatch risk as this risk reflects on the corporate balance sheet (Jin et al., 2006). Finally, pension funds with lower previous period funding ratios invest a larger fraction of risky assets to illiquid assets, supporting the results found in Basak and Shapiro (2001). A one standard deviation decrease in the previous period funding ratio increases the fraction of risky assets allocated to illiquid assets by 0.89 percentage points.

The remainder of this paper is organized as follows. Section 2 explains the liquidity and capital requirements of pension funds and in which way these requirements affect the illiquid assets allocation in a theoretical framework. The data description is given in Section 3. The model and results are discussed in Section 4. The robustness checks are in Section 5. Section 6 describes the implications of our theoretical framework for pension funds in different regulatory frameworks and Section 7 concludes.

2 Illiquid assets allocation: theory

Pension funds have access to a large pool of asset classes to invest in. A key responsibility of a pension fund is to optimize the asset allocation given its liability structure. This is known as Asset Liability Management (ALM). Here, we focus on a specific part of the ALM process: the strategic allocation to illiquid assets. Pension funds can invest in many different illiquid asset classes such as private equity, real estate, and infrastructure. For our theoretical framework the focus is on the aggregate illiquid assets allocation. In the empirical section we consider the different illiquid asset classes.

In deriving their strategic allocation to illiquid assets, pension funds assess the benefits and costs imposed by these investments. Important drivers of the investment decision are the risk-return trade-offs, the portfolio diversification benefits, and the ability of illiquid assets to hedge the pension fund's liabilities. We do not have access to the investment beliefs of individual pension funds regarding expected returns and risks of illiquid asset classes, or their correlations with traditional asset classes. What we do observe instead are the constraints pension funds face in making strategic investment decisions to illiquid assets: liquidity and capital requirements. First, we show in a theoretical model how these two requirements work, interact, and affect investment decisions. Second, there is large heterogeneity in liquidity and capital requirements across pension funds. Pension funds for instance differ substantially in their liability duration, hedging activities, and foreign investments. This allows us to test the theoretical predictions of our model empirically in Section 4. We now formally introduce the liquidity and capital requirements.

2.1 Liquidity requirements

A pension fund must have sufficient liquidity to fulfill its immediate obligations. The liquidity requirements of a pension fund consist of mainly two components: short run pension payments and collateral requirements on interest rate and currency derivatives. The cash required for pension payments is generally well predictable. The number of retirees and their benefits are well known. However, the cash needed for collateral requirements, is much less predictable. If the market value of a derivative declines, the pension fund is required to transfer cash or highly liquid short-term bonds to a margin account in order to limit the counter-party risk. Cash flows from margining on derivatives can become quite substantial, especially during financial crises. Pension payments can be seen as the expected liquidity requirement, whereas collateral requirements present liquidity risk. Liquidity problems arise when a pension fund lacks sufficient liquid resources to fulfill its immediate obligations.[3]

Investors facing liquidity risk should significantly reduce the allocation to illiquid assets in order to avoid states of the world in which it would be short liquidity and could not cover, e.g., pension payments. Theoretical studies from for instance Ang et al. (2014) and Gârleanu (2009) show this formally. Moreover, Ang et al. (2014) show that the reduction in the allocation to illiquid assets should be stronger when investors have higher short-term liquidity needs. From a theoretical perspective we would therefore predict that higher liquidity requirements restrict investments in illiquid assets. We will now discuss the effect of the liquidity requirement on the illiquid asset allocation in our framework in

[3]Salary payments to pension fund's staff, administrative expenses and investment costs are also sources that require short-term liquidity, but are generally small compared to the size of the pension fund and therefore outside the scope of this paper.

more detail.

2.1.1 Liquidity requirement for pension payments

The liquidity requirement in our model consists of two components: short-term pension payments and margin calls on derivatives. We start with the short-term pension payments and denote it by LR_P. It is the ratio of pension payments in the first year to the present value of total liabilities. Suppose we have an homogeneous group of pension participants with mortality rate λ that receive an annual pension payments of A. The level of pension payments in year t is given by

$$A \exp(-\lambda t). \tag{1}$$

Assuming a flat term-structure of interest rates r, the present value of all future pension payments equals

$$V = \int_0^\infty A \exp(-(r+\lambda)t)dt = \frac{A}{r+\lambda}. \tag{2}$$

Then, in relative terms, the short-term pension payments equal

$$LR_P = \frac{A}{A(r+\lambda)^{-1}} = r + \lambda. \tag{3}$$

The duration of the present value of all future pension payments V equals

$$D_V = -\frac{1}{V}\frac{dV}{dr} = \frac{1}{r+\lambda}. \tag{4}$$

Using (3) and (4), we can therefore rewrite the liquidity requirement from pension payments as

$$LR_P = \frac{1}{D_V}. \tag{5}$$

Equation (5) has an intuitive interpretation. The liability duration shows the weighted average time to maturity of the pension payments. In other words, it measures the average investment horizon of the pension fund. A high liability duration D_V implies less short-term payments as a small fraction of the present value of all future payments has to be paid out in the near future. In line with the findings in Ang et al. (2014), a high liability duration therefore creates opportunities to invest in illiquid assets. The inability to frequently trade illiquid assets is less of a restriction for a pension fund with a long liability duration.

2.1.2 Liquidity requirement for interest rate derivatives

Next to short-term pension payments, liquidity requirements also arise when the pension fund needs cash to meet margin requirements on derivatives. We consider margin requirements on interest rate swaps (this section) and currency forwards (Section 2.1.3). For model tractability we refer to the interest rate derivate portfolio as a position in a single receiver swap. Pension funds mainly use receiver swaps to hedge the interest rate risk embedded in the present value of the pension liabilities. In a receiver swap a pension fund pays a counter party a floating rate and receives a fixed rate over a certain notional amount. We denote the notional of the receiver swap by N and the duration of its fixed leg by D_R. The fraction of interest rate risk hedged with the receiver swap, again relative to the total value of liabilities V, is

$$\phi^R = \frac{N}{V}\frac{D_R}{D_V}.$$

In the remainder of the paper we refer to ϕ^R as the swap hedge ratio. We model the liquidity requirement on interest rate derivatives as the liquidity needed in case of a margin call. We consider an increase in the interest rate dr^+ as this leads to a margin call since it will lower the value of the fixed leg of the swap. In first-order approximation, the liquidity requirement from margin calls on interest rate derivatives then equals

$$MC_R = \phi^R D_V dr^+. \tag{6}$$

We could add a second-order, convexity, effect to (6). However, this has only a small effect on the quantitative results of the model and is, therefore, excluded here.

2.1.3 Liquidity requirement for foreign exchange derivatives

The liquidity requirement on foreign exchange derivatives also results from margin calls in case the value of the derivative portfolio decreases. Pension funds generally hedge exchange rate risk with currency forwards. We assume that the pension fund in our model has a position in a single forward contract. We model the liquidity requirement on foreign exchange derivatives as the liquidity demand from a margin call. We consider again an increase in the foreign exchange rate dFX^+ as this will lower the value of the forward contract and, thus, may result in a margin call. The liquidity requirement from margin calls on foreign exchange derivatives then equals

$$MC_{FX} = w^{FX} \phi^{FX} dFX^+, \tag{7}$$

where w^{FX} is the fraction invested in foreign assets as fraction of V and ϕ^{FX} is the foreign exchange hedge ratio relative to V.

We can now determine the total liquidity requirement by adding (3), (6), and (7). This gives the total liquidity requirement LR, relative to V, as

$$LR = \frac{1}{D_V} + \phi^R D_V dr^+ + w^{FX} \phi^{FX} dFX^+. \tag{8}$$

2.2 Capital requirements

Next to liquidity requirements pension funds also have capital requirements. Similar to banks and insurance companies, pension funds may be required by regulation to retain sufficient capital to be able to absorb losses in case of adverse events on financial markets or in longevity (Broeders and Pröpper, 2010). A pension fund generally does not have shareholders that provide equity. Instead, a pension fund's capital is the difference between the value of the assets and the value of the liabilities. In the US and Canada capital requirements are fixed, meaning that the funding ratio has to be at least 100 percent, regardless of a pension fund's risk-profile. In the Netherlands, the capital requirement is risk-based and calculated as a Value-at-Risk (VaR) risk measure. In fact, the required capital is calculated such that the probability that the funding ratio falls below 100 percent on a one-year horizon equals 2.5 percent. Pension funds calculate the capital requirement by applying a method prescribed by law. The method starts with deriving the individual capital requirements for the following risk factors: interest rate risk, equity and real estate risk, currency risk, commodity risk, credit risk, and longevity risk. The capital required for each of these risk factors is determined by the impact on the pension funds equity of prescribed shocks in the risk factor. Next the total capital requirement is determined by aggregating the individual requirements using a prescribed correlation matrix. In practice pension funds not always have sufficient capital. In that case a pension fund gets a 10 year recovery period to become again compliant with the capital requirement. The Dutch setting therefore is unique and allows us study the effect of capital requirements on the illiquid assets allocation for pension funds. All else equal, a higher capital requirement limits opportunities to invest in illiquid assets. For the purpose of our paper we only consider how much capital is required for interest rate and currency risk.

2.2.1 Capital requirement for interest rate risk

The root cause of interest rate risk is embedded in the present value of the future pension payments. Pension funds can hedge this interest rate risk not only with receiver swaps but also with bonds. In the Dutch regulation, the capital requirement is based on the part of the interest rate risk in the liabilities that is not hedged with swaps and bonds. We already introduced the swap hedge ratio (ϕ^R). The fraction of interest rate risk hedged with bonds is denoted by ϕ^B, or the bond hedge ratio. The pension fund invests fraction B/V in bonds with a bond duration denoted by D_B. Then ϕ^B is defined as

$$\phi^B = \frac{B}{V}\frac{D_B}{D_V}.$$

We model the capital requirement on interest rate risk as the capital demand for that part of interest rate risk that is not hedged with swaps or bonds. For that, we consider a decrease in the interest rate dr^-. An interest rate decrease will typically lower the funding ratio (as it will increase the value of the liabilities to a higher extent than it increases the value of the fixed income assets). The first-order approximation of the capital requirement for interest rate risk is given by[4]

$$CR_R = -(1 - \phi^R - \phi^B) D_V dr^-. \tag{9}$$

To keep the capital requirement from interest rate risk positive (9), we assume that pension funds never over-hedge, so that $\phi^R + \phi^B \leq 1$. In other words, we assume pension funds do not over-hedge their exposure to interest rate risk.[5]

2.2.2 Capital requirement for foreign exchange rate risk

Pension funds can hedge foreign exchange rate risk with currency forwards. Exchange rate risk occurs when pension fund's liabilities are in one currency and the investments are in another currency. The capital requirement for exchange rate risk depends on the exchange rate risk that is not hedged with forwards. We therefore consider a decrease in the foreign exchange rate dFX^-. A decrease in the foreign exchange rate lowers the funding ratio as it will decrease the value of the assets in the local currency of the pension fund. The capital requirement of a pension fund to exchange rate risk equals

$$CR_{FX} = -w^{FX}(1 - \phi^{FX}) dFX^-. \tag{10}$$

Adding (9) and (10) gives the total capital requirement CR, again relative to V, as

$$CR = -(1 - \phi^R - \phi^B) D_V dr^- - w^{FX}(1 - \phi^{FX}) dFX^-. \tag{11}$$

2.3 Total liquidity and capital requirements

In order to combine the liquidity and capital requirement, we assume that positive and negative shocks are equally likely for both the interest rate and foreign exchange rate. In other words, we assume for both interest rate and foreign exchange rate that the changes are identical in absolute value, or $dr^+ = -dr^- = dr$ and $dFX^+ = -dFX^- = dFX$. This is reasonable as pension funds cannot ex ante know whether an increase or decrease in the underlying risk factor occurs. The assumption furthermore implies that for both capital

[4]We again exclude the convexity effect here as it only has a small second-order effect on the quantitative results.

[5]This assumption is realistic as the value-weighted average of hedged interest rate risk across Dutch pension funds equals 40 percent, meaning $\phi^R + \phi^B = 0.40$.

requirements as well as margin calls the shocks are calibrated with the same probability on the same horizon. Then, (8) and (11) can be combined to obtain the following total liquidity and capital requirement

$$LR + CR = \frac{1}{D_V} + (1 - \phi^B) D_V dr + w^{FX} dFX. \tag{12}$$

Equation (12) does not depend on the swap hedge ratio. This is intuitive in our model as the liquidity requirement from the margin call on the swap cancels against the capital requirement. We therefore assume in our model that a pension fund can exchange a margin call on receiver swaps one-to-one for capital. As a result, ϕ^R does not appear in total requirement (12).[6] The more a pension fund hedges it's interest rate risk with swaps, the higher the liquidity requirement and equally lower the capital requirement. For the same argument, ϕ^{FX} does also not appear in total requirement (12).

Based on the analysis above we can also determine for which liability duration the total requirement $LR + CR$ is least constraining the investments in illiquid assets. Equating the first-order derivative of $LR + CR$ with respect to the liability duration D_V to zero, we get

$$\frac{d(LR + CR)}{dD_V} = -\frac{1}{D_V^2} + (1 - \phi^B) dr = 0, \tag{13}$$

so that the liability duration for which the total requirement $LR+CR$ is least constraining is

$$D_V^* = \frac{1}{\sqrt{(1 - \phi^B) dr}}. \tag{14}$$

Based on this we expect pension funds with a liability duration around D_V^* to have the highest exposure to illiquid assets.

We can illustrate how the liability duration affects the total requirement $LR + CR$ in a stylized, but representative, example. We take the shocks to calculate the liquidity and capital requirement to be predetermined and equal to $dr = 0.5\%$ and $dFX = 25\%$. These values are comparable to the predetermined shocks used to calculate the required capital for Dutch pension funds and are also in line with the shocks used under Solvency

[6] In the Dutch regulation, this is not entirely true in practice, because the total capital requirement takes into account a diversification effect between interest rate risk and other risk factors. This diversification effect however only has a marginal second order effect on the numerical solution of the model.

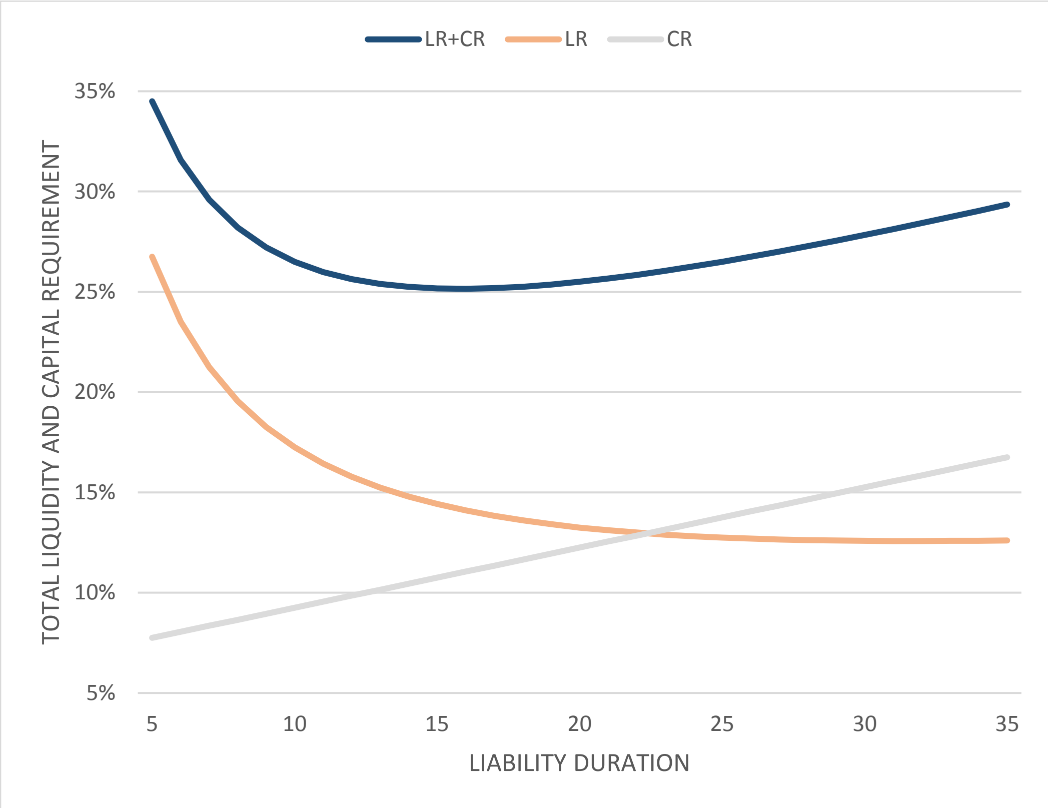

Figure 1: **Liquidity requirement, capital requirement, and their sum as a function of liability duration**
We use the following parameter values $dr = 0.5\%$, $\phi^R = 20\%$, $\phi^B = 20\%$, $dFX = 25\%$, $\phi^{FX} = 50\%$, and $w^{FX} = 50\%$.

II regulation. We use parameter values in line with the average Dutch pension fund: $\phi^R = 20\%$, $\phi^B = 20\%$, $\phi^{FX} = 25\%$, and $w^{FX} = 50\%$. Figure 1 show how the liquidity and capital requirements, and their sum, depend on the liability duration (D_V). The graph shows that the liquidity requirement is a convex decreasing function of D_V, whereas the capital requirement is, in our model, a linearly increasing function of D_V. the total requirement $LR + CR$ is therefore first increasing and then decreasing in D_V. A low liquidity and capital requirement implies that the pension fund has more opportunities to invest in illiquid assets. Thus, our model predicts that the impact of D_V on the share of risky assets invested in illiquid assets follows the inverse shape of the total liquidity and capital requirement in Figure 1. In other words, D_V has a hump-shaped effect on the share of risky assets invested in illiquid assets. We will see in Section 4 that this is confirmed by our empirical analysis.

The economic interpretation of Figure 1 is as follows. For old pension funds, i.e., pension funds with a low liability duration, a one year increase in the liability duration generates more opportunities to invest in illiquid assets as the liquidity requirement decreases more than the increase in the capital requirement. For young pension funds, i.e., pension funds with a high liability duration, the high liability duration will give them less opportunities to invest in illiquid assets as the decrease in the liquidity requirement is lower than the increase in the capital requirement. In Figure 1 the reflection point is at $D_V = 15.8$. This reflection point will be different for other parameter configurations.

2.4 Summary of the hypotheses

In this section we summarize the hypotheses following from our theoretical framework. As explained above, we expect the impact of liability duration on the illiquid assets allocation to be hump-shaped. We will assess this hump-shaped relationship by adding a quadratic term of liability duration to the regression model. Based on the total requirement $LR+CR$ we expect that the swap hedge ratio and the foreign exchange hedge ratio have no effect on the fraction of risky assets invested in illiquid assets. Both the swap and foreign exchange hedge ratios do not appear in (12) because the liquidity and capital requirement cancel out against each other.

Two control variables are worth mentioning already. First, according to (12) we expect that the bond hedge ratio will positively impact the illiquid assets allocation. If a pension fund hedges more interest rate risk embedded in the present value of the liabilities with bonds it will unlock some of its risk budget. This can be used to invest more in illiquid assets. Second, a pension fund that invests more in non-euro dominated assets will be exposed to more currency risk. This will seize some of its risk budget that therefore cannot be used to invest more in illiquid assets.

Table 1 summarizes the predictions of the different variables on the illiquid assets allocation. In the empirical results we will focus on three regression specifications. The main regression uses the fraction of risky assets invested in illiquid assets as dependent variable. We explain in detail why we use the fraction of risky assets allocated to illiquid assets as dependent variable in Section 4. In addition to that we will also assess the impact of liability duration and hedging on the allocation to illiquid assets and on the allocation to risky assets.

Table 1: **Hypotheses**
This table shows the predictions of the model parameters on the fraction of risky assets allocated to illiquid assets.

Model parameters	Fraction illiquid assets $\frac{w^{ILLIQ}}{w^{RISKY}}$
Liability duration D_V	hump-shaped
Swap hedge ratio ϕ^R	no effect
Foreign exchange hedge ratio ϕ^{FX}	no effect

3 Data

We use data of N=219 Dutch pension funds including their asset allocations, interest rate, and currency derivatives, and other characteristics such as size and pension fund type. The data are free from reporting biases as pension funds report mandatory. We only consider defined benefit pension funds as those are subject to capital requirements. Defined benefit pension funds guarantee retirement benefits that depend on an employee's earnings history and years of service. This proprietary data is obtained from the quarterly statements Dutch pension funds mandatory report to De Nederlandsche Bank, the prudential supervisor. The sample runs from the beginning of 2012 to the end of 2017, or 24 quarters. As the reporting requirements changed as of 2015, we carefully merge data before 2015 with the data from the start of 2015 to ensure consistency in the reported variables.[7] We exclude pension funds that are liquidated during the sample period. Such a liquidation scenario means that the pension fund will gradually transfer assets and liabilities to either another pension funds or to an insurance company. Often this is being done to enhance cost efficiency. The gradual transfer of assets may result in non-representative asset allocations. We therefore exclude these pension funds. As Dutch pension funds cannot go bankrupt, there is no survivorship bias.[8] Table 2 shows that in terms of total AUM we only exclude a very minor fraction, about 2 percent, by not incorporating pension funds that are liquidated during the sample period.

[7]In 2015 the reporting requirements distinguish a larger scale of different asset categories. Besides that, the total amount invested in each asset category was divided into larger subsets in order to improve knowledge on pension fund investment behavior.

[8]As a measure of last resort pension funds can reduce accrued pension benefits.

A - Illiquid assets

Our data distinguishes between the following 12 assets classes: government bonds, stocks in mature markets, credits, stocks in emerging markets, inflation index-linked bonds, cash and short-term receivables, listed indirect real estate, commodities, non-listed real estate, mortgages, private equity, and hedge funds.[9] The sum of all asset classes except government bonds, inflation-index bonds, and cash and short-term receivables is defined as the allocation to risky assets (w^{RISKY}).[10]

To distinguish between illiquid and liquid assets we need to define the concept of liquidity. An asset is considered less liquid if the investor cannot quickly sell a significant quantity of the asset at a price near fundamental value. In illiquid markets it is generally more difficult to quickly find counter-parties to trade with at a price close to the asset's fundamental value. Asset classes such as private equity require counter-parties to have significant capital and particular knowledge about the asset class, which are both often limited in supply. Therefore, transactions costs of illiquid assets can become substantial. For some illiquid assets, legal impediments make it impossible to trade for a particular time period at all, such as lock-up periods some hedge funds and private equity funds require. Certainly, each asset or asset class has some (time-varying) degree of liquidity, e.g., trading in a corporate bond may become illiquid if the corporate comes close to bankruptcy. As a result, no clear line can be drawn to distinguish a liquid asset class from an illiquid one. However, some asset classes are substantially more illiquid than others in terms of the three dimensions mentioned above. As pension funds are long term investors, we use immediacy as the key criterion to distinguish between liquid and illiquid asset classes. We classify the sum of non-listed real estate, mortgages, private equity, and hedge funds allocations as the total allocation to illiquid assets (w^{ILLIQ}). Private equity allocation includes both listed and non-listed private equity, infrastructure investments and micro finance investments. The allocation to private equity contains only the commitments already made, so future commitments are not included. The asset category mortgages contains mortgage-backed securities and direct mortgage lending.

The sum of allocations to stocks in mature markets, credits, stocks in emerging markets, listed indirect real estate and commodities is defined as total allocation to liquid risky

[9] Credits contain all credit related products, e.g. corporate bonds, bank loans, and syndicated loans.

[10] Privately issued inflation-index bonds constitute only a small portion of the market. As a result, we assume that all inflation-index bonds are issued by governments.

assets (w^{LIQ}). So, the allocation to risky assets is equal to the sum of the allocation to risky illiquid assets and to risky liquid assets

$$w^{RISKY} = w^{ILLIQ} + w^{LIQ}.$$

Pension funds report both strategic and actual asset allocations. We focus on the strategic asset allocations as those better reflect the decisions made by pension funds. Furthermore, the actual asset allocation is less useful as it may deviate from the strategic one due to market fluctuations and imperfect re-balancing (Bikker et al., 2010). In the robustness checks we however show that our main results still hold using actual rather than strategic asset allocations.

Table 3 presents the summary statistics. Panel A highlights the strategic asset allocations. The averages are equally weighted over pension funds. Government bonds, stocks mature markets and credits are the most important asset classes, with average allocations of 33, 29 and 18 percent respectively. Of the illiquid asset classes, non-listed real estate is the largest asset class with an average allocation of 4 percent. The 90th percentile shows that 10 percent of the pension funds invest more than 12 percent in this asset class. Pension funds on average invest 2 percent in mortgages. The other two illiquid asset classes are around 1 percent allocations on average. Panel A also shows the mean and standard deviation of the actual asset allocations between brackets. The difference are small compared to the strategic asset allocation suggesting that pension funds do not substantially deviate from their strategic asset allocations.

Turning to Panel B, we see that the average allocation to the illiquid assets equals 8 percent. Approximately one-third of Dutch pension funds do not invest in illiquid assets at all. The 90th percentile shows that 10 percent of the pension funds allocate over 20 percent of their total AUM to illiquid assets.

Table 4 shows that the strategic illiquid assets allocation varies over the time period 2012-2017. This holds for both the aggregate illiquid assets allocation as the separate illiquid asset classes. Pension funds generally adjust their asset allocation every 3 years. This implies pension funds on average change there illiquid assets allocation twice during the sample period. However, we see in the data that some pension funds change their strategic asset allocation more frequently, whereas none of the pension funds never changes the allocation over the sample period. This is probably due to the fact that pension funds gradually change their allocation over time.

B - Liability duration

Pension funds report the modified duration of their liabilities (D_V). The liability duration is summarized in Panel B of Table 3. The average liability duration equals 18.9 years. However, 10 percent of the pension funds have a liability duration below 14.6 years and 10 percent have a liability duration in excess of 23.9 years. This shows there is quite some variation in the average investment horizon of pension funds.

C - Collateral requirements

Unfortunately pension funds do not report the swap hedge ratios and the foreign exchange hedge ratios. However, the data do allow us to calculate the collateral requirements in case of an adverse event in the underlying risk factor, which we argue are good proxies for the swap hedge ratio and the foreign exchange hedge ratio.[11] We will now explain in detail how we measure the collateral requirements.

Pension funds report the market value of the interest rate and currency derivatives. In addition, they also report the simulated values of the derivatives after four predetermined shocks in the underlying risk factors. The shocks are performed on the underlying risk factor and not on the market value of the derivative itself. In case of interest rate derivatives, the four shocks imply a decrease (increase) in the term structure of interest rates with 0.5 percentage points and 1 percentage points respectively. In case of currency derivatives, the four shocks imply an appreciation (depreciation) of the foreign currency with respect to the euro by 12.5 percentage points and 25 percentage points respectively.

We define the collateral requirements on interest rate derivatives (CRr) as the absolute difference between the market value of the portfolio of derivatives after a predetermined shock, MVr_s, minus its current market value, MVr_c. We express the absolute value of the change relative to the pension fund's total assets under management (AUM)

$$CRr = \frac{|MVr_s - MVr_c|}{AUM}.$$

[11] As of 2015, pension funds report the total bond hedge ratio and the total swap hedge ratio. The correlation between the actual swap hedge ratio and our computed collateral requirement on interest rate derivatives equals 0.75.

We define the collateral requirements on currency derivatives ($CRfx$) as the absolute difference between the market value of the portfolio of derivatives after a predetermined shock, $MVfx_s$, minus its current market value, $MVfx_c$. We express the absolute value of the change relative to the pension fund's total AUM

$$CRfx = \frac{|MVfx_s - MVfx_c|}{AUM}.$$

In the model specification the collateral requirements are determined by using an increase in the interest rate of 1 percentage points and an increase of the foreign currency relative to the euro of 25 percentage points. In Section 5, we show that our results are robust against the size of the predetermined shock. As we only observe the aggregate market value of interest rate and currency derivatives, we cannot observe each interest rate and currency derivative individually. This implies we assume that all derivative contracts have collateral requirements.

The collateral requirements on interest rate and currency derivatives are summarized in Panel B of Table 3. The collateral requirements from interest rate derivatives and currency derivatives are approximately of the same order of magnitude. The average collateral requirement on both interest rate and currency derivatives equals 5 percent of total AUM. The 10th percentiles are in both cases equal to zero, revealing that part of the pension funds do not hedge interest rate and currency risk at all.

D - Control variables

Our theoretical model shows that the bond hedge ratio (ϕ^B) and the fraction invested outside the euro area (w^{FX}) affect the illiquid assets allocation. We therefore also include those two variables in the regression. Table 3 shows that pension fund on average hedge 25 percent of their interest rate risk with bonds. The average fraction investments outside the euro area equals 22 percent on average.[12]

As control variables we include pension fund type ($Type$), size ($Size$), the required funding ratio (Rfr) and the previous period actual funding ratio (Fr). We distinguish three different pension fund types. The dataset covers 55 industry-wide pension funds, 10

[12]Notice that in our theoretical model we expressed all results relative to the liabilities. Here we take both the bond hedge ratio and the fraction invested outside the euro area as fraction of total AUM to make the quantities easier to interpret. Expressing the quantities in AUM or liabilities does however not affect our empirical analysis.

professional group pension funds and 154 corporate pension funds. Industry-wide pension funds are generally mandatory pension funds and organize pensions for a specific industry or sector, e.g., civil servants and hospital staff. Professional group pension funds provide pensions for a single profession such as hairdressers and doctors. Corporate pension funds arrange pensions for a particular company. We measure size by the log of total assets under management.

The required funding ratio to comply with regulation is also used as a control variable. It is determined risk-based, depending on the specific risk profile of a pension fund. We include the required funding ratio as control to take into account different risk appetites of pension funds. For instance, young pension funds (high liability duration) could substantially differ in their risk-appetite compared to old pension funds (low liability duration), potentially driving the effect of liability duration on the illiquid assets allocation. Furthermore, pension funds that hedge a relative small part of their interest rate risk or currency risk, could be the pension funds that take more risk in general, potentially driving the effects of hedging on the illiquid assets allocation.

The actual, previous period, funding ratio is also included in the analysis. From the literature on risk-taking behavior of pension funds, the actual funding ratio could either have a positive or a negative effect on the pension fund's illiquid assets allocation. The capital requirement might not be binding if the pension fund's funding ratio is far above or below the required funding ratio. Basak and Shapiro (2001) show that compared to normal circumstances, investors take relatively more risk in worst case scenarios when they are subjected to a VaR requirement. On the other hand, Rauh (2009), using US corporate defined benefit pension funds data, finds that poorly funded pension plans and firms with weak credit ratings allocate a larger share of their pension fund assets to safer securities such as cash and government debt.

The pension fund's size, required funding ratio and actual funding ratio are summarized in Panel B, Table 3. The 10th and 90th percentile of the log of total AUM reveals that the distribution is right skewed. This shows that the largest pension funds in our sample are considerably larger compared to the mean pension fund. The average required funding ratio equals 116 percent and does vary from 110 to 123 percent across pension funds. The actual average funding ratio equals 109 percent, which is substantially below the required funding ratio of pension funds.

Table 5 splits the sample in pension funds that invest and do not invest in illiquid assets. Pension funds that do not invest in illiquid assets take less risk in general, having on average a 10 percentage points lower risky assets allocation. The table also reveals that the two groups differ in size, where the average size of pension funds that do not invest in illiquid assets in considerably smaller. On other dimensions both group of pension funds are comparable.

4 Allocation to illiquid assets: empirical results

In order to assess the relationship between a pension fund's illiquid assets allocation and liquidity and capital requirements, we estimate a static random effects Tobit model.[13] The Tobit model controls for left-censoring of the allocation to illiquid assets at zero. This is necessary as a substantial number of pension funds does not invest in illiquid assets at all. Asset allocation decisions are typically first made to different asset classes such as stocks and bonds. In a next step, asset allocations are determined within each asset class (Binsbergen et al., 2008). Following this decision making process, we first analyze the aggregate illiquid assets allocation. As illiquid asset classes differ in their degree of immediacy, we look at the illiquid asset classes separately in the next section.

We will not assess the illiquid assets allocation directly. Instead we will take the fraction of risky assets invested in illiquid assets as our dependent variable. The main reason to look at this fraction is to prevent the impact of mechanical effects. For instance, suppose a pension funds invests more in bonds, this automatically results in a lower risky asset allocation and therefore, potentially, also a lower allocation to illiquid assets. Dutch pension funds invest most of their fixed income portfolio in the euro area, whereas the risky portfolio is generally invested more broadly. Currency hedging is therefore directly related to the risky asset allocation. A positive effect of currency hedging on the illiquid assets allocation could therefore simply be mechanical.

In alternative model specifications we also use the allocation to illiquid assets (w^{ILLIQ}) and the risky assets allocation (w^{RISKY}) as dependent variables. In the latter case we estimate a standard random effects model as there is no censoring around zero.

[13]Random effects structure corrects for time-invariant characteristics of the pension fund that we do not observe and potentially play a role.

The general model specification is

$$\frac{w_{it}^{ILLIQ}}{w_{it}^{RISKY}} = \beta_0 + \beta_1 D_{V,it} + \beta_2 D_{V,it}^2 + \beta_3 CRr_{it} + \beta_4 CRfx_{it} + \beta_5 \phi_{it}^B + \beta_6 w_{it}^{FX} \qquad (15)$$
$$+ \beta_7 Size_{it} + \beta_8 Type_i + \beta_9 Rfr_{it} + \beta_{10} Fr_{it-1} + \lambda_t + \epsilon_{it}.$$

where i indicates pension fund i, $i = 1, ..., N$ and t end of the quarter t, $t = 2012Q1, ..., 2017Q4$. The main explanatory variables of interest are the pension fund's liability duration (D_V), the square of the liability duration (D_V^2), the collateral requirements on interest rate derivatives (CRr), the collateral requirements on currency derivatives ($CRfx$), the bond hedge ratio ϕ^B, and the fraction of total foreign investments w^{FX}. To link the main regression specification directly to our theoretical framework, we recall from the previous section that CRr proxies for ϕ^R and $CRfx$ proxies for ϕ^{FX}. The control variables are the log of total AUM ($Size$), the pension fund type ($Type$), the required funding ratio (Rfr) and the lag of the actual funding ratio (Fr). We include dummies for the pension fund type, where the reference group are the industry-wide pension funds. The professional group pension fund is denoted by dummy $Prof$ and the corporate pension fund is denoted by dummy $Corp$. The prolonged period of low interest rates may have made pension funds to increase their allocation towards illiquid assets to seek for higher yielding investments (Boubaker et al., 2017). Therefore, we control for time-fixed effects (λ) in all our model specifications.

There are not sufficient long-term (government) bonds available in the market to cover all pension liabilities. This issue is more severe for pension funds with long liability duration. Therefore, it seems intuitive that pension funds with a higher liability duration are more likely to hedge interest rate risk through derivatives. In other words, D_V and CRr may be correlated. Table 6 shows a correlation between D_V and CRr of 0.40 and as a result, collinearity seems not an issue. This implies the results on D_V and CRr can be interpreted separately.[14]

[14]We also run our models to test for a possible interaction between liability duration and collateral requirements. The interaction term between both variables however is statistical not different from zero in all of the model specifications. Results are available upon request.

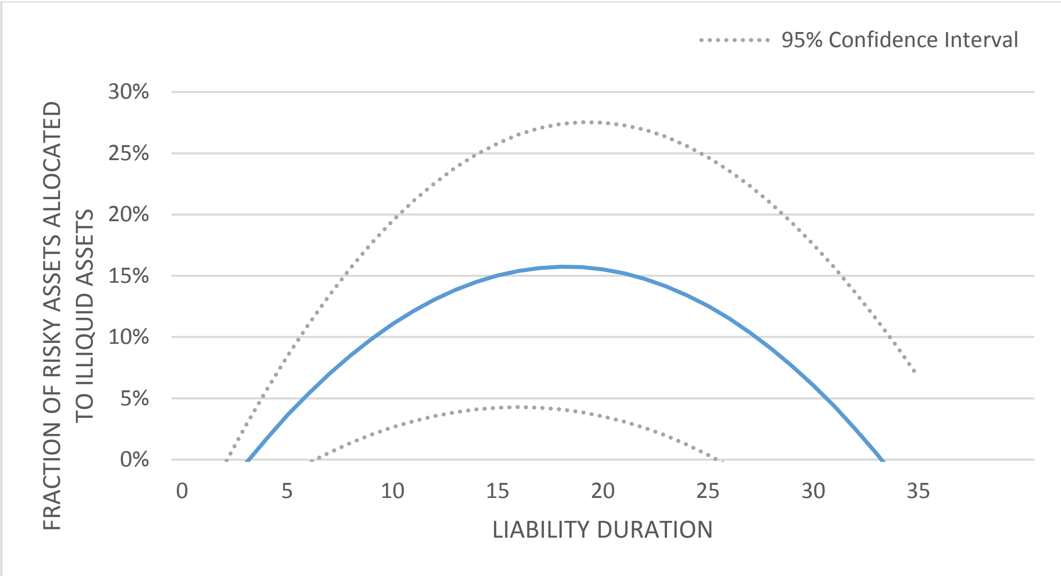

Figure 2: **The effect of the liability duration on the fraction of risky assets allocated to illiquid assets**
The calculations are based on assuming an industry-wide pension fund which has average foreign exchange risk hedging activities, average size, and average lag funding ratio (other variables are set equal to zero as they are not statistically significant).

A - Liability duration

Table 7 shows the results of the main model specification (15). The first column shows that liability duration has a positive effect on the fraction of risky assets allocated to illiquid assets, whereas the square of the liability duration has a negative impact. Both coefficients are statistically significant at the 1 percent significance level. Up to a liability duration of 18 years ($\frac{\partial w^{ILLIQ}/w^{RISKY}}{\partial D_V} = \beta_1 + 2\beta_2 D_V = 0 \rightarrow D_V = -\frac{\beta_1}{2\beta_2}$), the effect of liability duration is positive. After this point however, the effect is reversed. A liability duration increase from 10 to 11 years is followed by an increase in the fraction of illiquid assets of 1.07 percentage points. A liability duration increase of 25 to 26 years leads to a decrease in the allocation to illiquid assets of 1.02 percentage points.[15] Figure 2 shows the hump-shaped impact of liability duration on the fraction of the risky assets allocated to illiquid assets.

The results are in line with the theoretical predictions of our model. Up to a liability

[15]Notice that the coefficients are estimates based on the uncensored latent variable, not the observed outcome. The coefficients are the right interpretation for all observations on the dependent variable, w^{ILLIQ}/w^{RISKY}, above zero. In order to get the effect on the actual observed dependent variable, the coefficient estimates have to be multiplied by the probability of the dependent variable being above zero.

duration of 18 years, the liquidity requirement decreases faster than the capital requirement increases. A pension fund with a long liability duration has less short-term liabilities relative to a pension fund with a short liability duration. A longer liability duration implies it is less of a constraint for a pension fund not being able to trade frequently in illiquid assets. Beyond a liability duration of 18 years however, the capital requirement increases faster than the liquidity requirement decreases. This lowers the opportunity to invest in illiquid assets.

As an alternative specification we use the allocation to illiquid risky assets w^{ILLIQ} (Table 7, Column (2)). Again, the hump-shaped impact on the illiquid assets allocation appears. We also use as alternative specification the allocation to risky assets w^{RISKY}. Figure 3 and Table 7, Column (3) show that the liability duration has a negative impact on the risky assets allocation. Liability duration squared has a positive and significant impact on the risky assets allocation.

The increase in the risky asset allocation for higher liability durations coincides with the findings in Andonov et al. (2017), who show that the investment policy of public and private European and Canadian pension funds and private US pension funds is more aggressive for less mature pension funds. However, we find that mature pension funds invest more in risky assets compared to pension funds with an average liability duration. We explain this by a looser capital requirement for mature pension funds. This capital requirement is absent for many other countries including the US where the capital requirement is not risk-based.

B - Collateral requirements

Table 7 shows that the collateral requirements of interest rate risk hedging (CRr) do not have an effect on the allocation to illiquid assets. This is in line with the theoretical predictions of our model: the liquidity and capital requirement cancel out against each other. However, we do find that collateral requirements on currency forwards have a significant and positive impact on the illiquid assets allocation. This finding is not in line with the theoretical predictions of our model. Talking to practitioners we learned that foreign exchange derivatives do not always have collateral requirements. In that case the liquidity and capital requirement would not, as in our theoretical framework, cancel out against each other. Instead, the decrease in the capital requirement is stronger than the

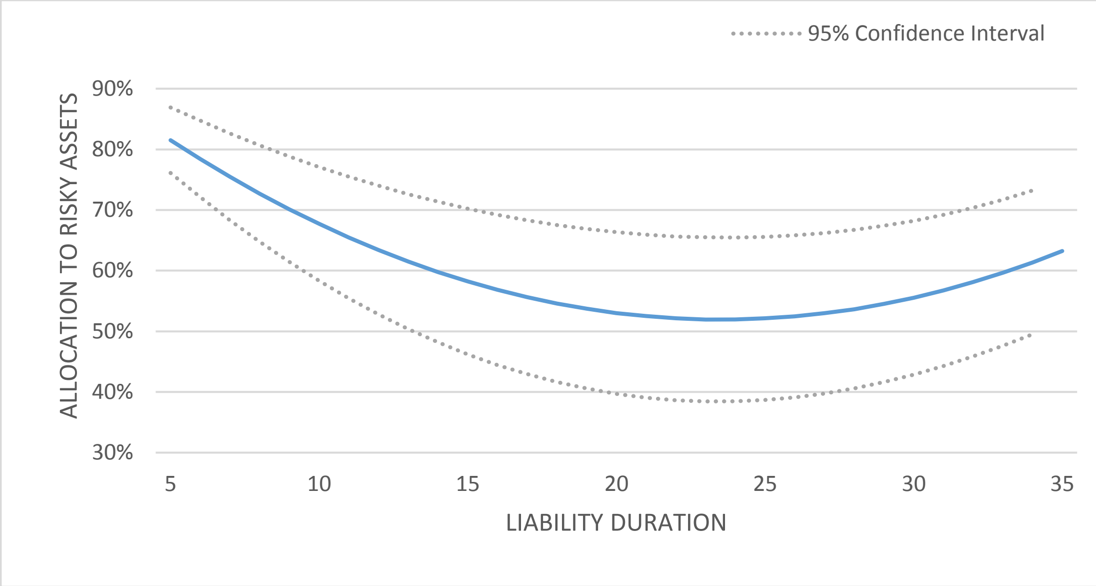

Figure 3: **The effect of the liability duration on the risky assets allocation**
The calculations are based on assuming an industry-wide pension fund which has average foreign exchange risk hedging activities, average bond hedging activities, average foreign investments, average size, and average lag funding ratio (other variables are set equal to zero as they are not statistically significant).

increase in the liquidity requirement in absence of collateral requirements. A one standard deviation increase in the collateral requirements (an increase of 0.04 $CRfx$) implies an increase in the fraction of risky assets allocated to illiquid assets of approximately 0.71 percentage points. The average fraction of risky assets allocated to illiquid assets of the pension funds that have a positive allocation to illiquid assets equals 13 percent. This implies a relative increase in the fraction of risky assets allocated to illiquid assets of approximately 5.5 percent.

The impact of collateral requirements on the allocation to risky assets is shown in Table 7, Column (3). The findings are comparable to the effects of the fraction of risky assets invested in illiquid assets. Notice that we control for the total fraction invested in foreign currencies such that the results we obtain are not mechanical. A one standard deviation increase in the collateral requirement (an increase of 0.04 $CRfx$) implies an increase in the risky assets allocation of approximately 1.64 percentage points. This implies a relative increase in the risky asset allocation of 2.6 percent. Taken together, larger foreign exchange hedge ratios increase the allocation to risky assets and a larger fraction of the risky assets allocation becomes illiquid.

Another explanation that we do not find different results for interest rate and currency hedging is the following. A margin call in case of interest rate derivatives due to an increase in the interest rate is associated with a decrease in value of other fixed income securities as well. If there is not enough cash at hand, pension funds have to use a relative larger part of their short-term liquid bonds as collateral. In case of a margin call on currency derivatives, the value of the assets however increases. This increase is the result of the increased value of the non-euro investments. In this case, if there is not enough cash at hand, pension funds have to use a relative smaller part of their eligible, liquid assets as collateral.

C - Control variables

We now discuss the effects of the control variables we employ. We do not find any statistically significant effects of the bond hedge ratio, although the sign is in the direction as predicted by our theoretical framework. Looking at the allocation to illiquid assets and risky assets we see that the bond hedge ratio negatively affects both allocations. This results follows mechanically since hedging interest rate risk with bonds is positively related to the allocation to bonds, and thus lowers the allocation to risky assets.

We also do not find an effect of foreign investments on the fraction invested in illiquid assets, although again the sign of the effect is in line with our model. When considering the illiquid assets allocation only, the fraction invested in foreign currency has again no impact, but the sign has the right direction. Looking at the risky assets allocation, the fraction invested in foreign assets negatively impacts the risky assets allocation. Investing more in foreign currencies keeping hedging activities fixed, increases the capital requirement and therefore limits opportunities to invest in risky assets. A 10 percentage points increase in the fraction invested in foreign assets decreases the risky assets allocation with 1.35 percentage points.

Furthermore, Table 7 shows that size has a positive and significant impact on the allocation to illiquid assets. A pension fund that is ten times larger in terms of total assets under management invests a 7.4 percentage points higher fraction of risky assets allocated to illiquid assets. Illiquid assets are generally complex products and therefore the pension fund needs to have sufficient knowledge to be able to manage the risk of those assets classes. The larger a pension fund, the better the pension fund can afford to pay high costs to make complex investments decisions or hire external managers to make those decisions. These findings are consistent with Andonov (2014) and Dyck and Pomorski (2016), who show that the increase in the allocation to illiquid assets is relatively more pronounced for large institutional investors. Moreover, Stoughton and Zechner (2011) argue that economies of scale in alternative assets exist because only large investors can afford to pay high fixed search costs to identify profitable projects or skilled external managers. On top of that, larger institutional investors are more qualified to access good quality projects at lower fees because they have more negotiation power (Broeders et al., 2016). Table 7 also shows that larger pension funds invest more in risky assets in general, although the economic impact is much smaller. A pension fund that is ten times larger invests 2 percentage points more in risky assets.

We also find that corporate pension plans invest less in illiquid assets compared to industry wide pension plans. Relative to the latter, corporate pension funds invest a fraction of 7.6 percentage points less of their risky assets allocation in illiquid assets. We believe that this difference is due to the fact that a corporate is required to report on its pension fund in the annual accounts. Furthermore, the riskiness of the pension plan impact the risk profile of their corporate (Jin et al., 2006). An additional explanation is that corporate pension funds are to a higher extent exposed to sponsor default risk compared to compulsory and professional group pension funds. Therefore, they are less willing to take risk (Broeders, 2010).

Finally we discuss the results of the funding ratio on the fraction of risky assets invested in illiquid assets. The required funding ratio does not affect the fraction allocated to illiquid assets, however the lag of the actual funding ratio affects the fraction invested in illiquid assets negatively. This implies that pension funds with lower last period funding ratio invest a larger fraction of their risky assets in illiquid assets. This result supports the finding by Basak and Shapiro (2001), namely that pension funds for which the VaR requirement is more binding take additional risk. A one standard deviation decrease in the previous period funding ratio increases the fraction of risky assets allocated to illiquid assets by 0.89 percentage points. Pension funds also increase the total risky assets allocation when previous period funding ratio decreased. In other words, a lower previous period funding ratio implies a higher total risky assets allocation and a larger fraction of the risky assets allocation becomes illiquid.

4.1 Empirical results separate illiquid asset classes

So far, we treated illiquid asset classes as a homogeneous group. However, the degree of immediacy may differ across separate illiquid asset classes. For instance, the typical time between transactions for residential housing is 4-5 years, although it can vary from months to decades (Hansen, 1998) and (Miller et al., 2011). The average time between transactions is relatively high in case of private equity. Private equity investments generally run for 10 years and trading before a contract expires is unusual (Metrick and Yasuda, 2010).

Table 8 shows the results for the four illiquid asset classes separately. The hump-shaped effect of the liability duration on the fraction of risky assets allocated to illiquid assets is significantly present in all four asset classes. The cut-off point where the marginal benefits (lower liquidity requirement) and the marginal costs (higher capital requirement) of a higher liability duration are equal, is close to the aggregate cut-off point of 18 for the overall fraction of risky assets allocated to illiquid assets.

The results of swap hedge ratios are however mixed across the different asset classes. Consistent with the aggregated results, the swap hedge ratio does not affect the allocation to real estate and mortgages. In case of private equity, the swap hedge ratio positively affects the real estate allocation. Notice that the economic magnitude is however small. A one standard deviation increase in collateral requirement leads to an increase of the fraction of risky assets allocated to private equity of 0.23 percentage points. On the other hand, the swap hedge ratio negatively affects the allocation to hedge funds. The results for hedge funds should however be interpreted with care for mainly two reasons. First, the number of uncensored observations is relatively small compared to the total number of observations. Second, lock-up periods for hedge funds received negative publicity since the recent financial crisis, as investors who tried to withdraw funds to meet liquidity needs where unable to do so. This likely also plays a prominent role in the allocation to hedge funds.

Also the results for foreign exchange hedge ratios are mixed across different asset classes. The foreign exchange hedge ratio does not affect the allocation to hedge funds and negatively affects the allocation to private equity. A one standard deviation increase in collateral requirement leads to an increase in the fraction of risky assets allocated to private equity of 0.80 percentage points.

The required funding ratio also has different effects on illiquid asset classes separately.

Pension funds with higher required funding ratios invest more in private equity, whereas less in mortgages. This reveals that pension funds with higher tolerance for risk might prefer certain illiquid assets over others.
These different findings compared to the aggregate illiquid assets allocation indicate that strategic decisions made at the top level do not have to be implemented at each individual asset class level. What matters is that the overall investment policy, risk exposures and liquidity profile are in accordance with the policy set by the board of trustees.

5 Robustness checks

The key results largely hold for the separate asset classes. Now we turn to the robustness checks. We consecutively look at the impact of liquidity and capital requirements on the actual instead of the strategic asset allocation, we take an alternative measure of liability duration and an alternative measure of collateral requirements.

5.1 Actual asset allocation

In the main regression we use strategic asset allocations. In this section we analyze the impact of liquidity and capital requirements on the actual asset allocations. Table 9 shows that our main theoretical predictions are supported for the actual asset allocations. First, the liability duration has a hump-shaped effect on the fraction of risky assets allocated to illiquid assets. Second, hedging of interest rate and currency risk does not affect the fraction of risky assets allocated to illiquid assets. The most important difference compared to the strategic asset allocation is that currency hedging becomes insignificant when using actual allocations. Although these results seem to better support or theoretical predictions, using actual asset allocations instead of strategic onces might result in effects that are (partly) driven by the performance of the different asset classes or imperfect re-balancing.

5.2 Alternative measure of liability duration

The liability duration of the pension fund is an implicit measure of the maturity of a pension fund. The higher the liability duration, the less short-term pension payments and thus the higher the number of young participants. Although we do not have information on the exact demographics of the pension fund participants, we do however have information on the total pension payments and the value of the liabilities per year. The ratio of pension payments to liabilities is an alternative measure for the maturity of the pension fund (De Haan, 2017). If this ratio is high, a larger part of the pension fund's participants consists of retirees and pension payments relative to liabilities are high.

In this robustness check we replace the liability duration by the ratio of pension payments to liabilities ($Benefits$).[16] Table 10 shows that using this alternative measure also results in a hump-shaped impact on the fraction of risky assets allocated to illiquid assets. Up to a ratio of 4.8 percent, the fraction of risky assets allocated to illiquid assets is positively affected.[17] After this point, the effect is reversed. Column (3) of Table 10 shows that the hump-shaped effect is absent for the allocation to risky assets.

In Section 2 we define the liquidity requirement from pension payments as the pension payments to be paid in the first year. In our theoretical framework the ratio of pension payments to liabilities is approximated by $\frac{1}{D_V}$. Figure 4 provides evidence that the fitted curve for the observed ratios of pension payments to pension liabilities is indeed a convex and decreasing function in line with the theoretical framework. This confirms that the inverse of the liability duration is a good proxy for the liquidity requirement from pension payments.

5.3 Alternative measure of collateral requirements

In our main model specification, we use a 1 percentage point increase in the interest rate as predetermined shock in order to calculate the potential margin calls due to interest rate hedging. We also use a 25 percentage points increase in the foreign currency relative to the euro as the predetermined shock in case of currency derivatives. In Table 11 we use a predetermined shock in the interest rate of 0.5 percentage points and an appreciation of the foreign currency of 12.5 percentage points. Table 11 shows that our results are robust against the choice for the predetermined shocks in order to proxy for the interest rate risk and currency risk hedging activities of pension funds.

[16] We only include observations at the end of each year as the pension payments are only available on an annual basis. The sample period is 2012-2016, as the pension payments for the year 2017 are not available yet.

[17] $\frac{\partial w^{ILLIQ}/w^{RISKY}}{\partial Benefits} = \beta_1 + 2\beta_2 Benefits = 0 \rightarrow Benefits = -\frac{\beta_1}{2\beta_2}$.

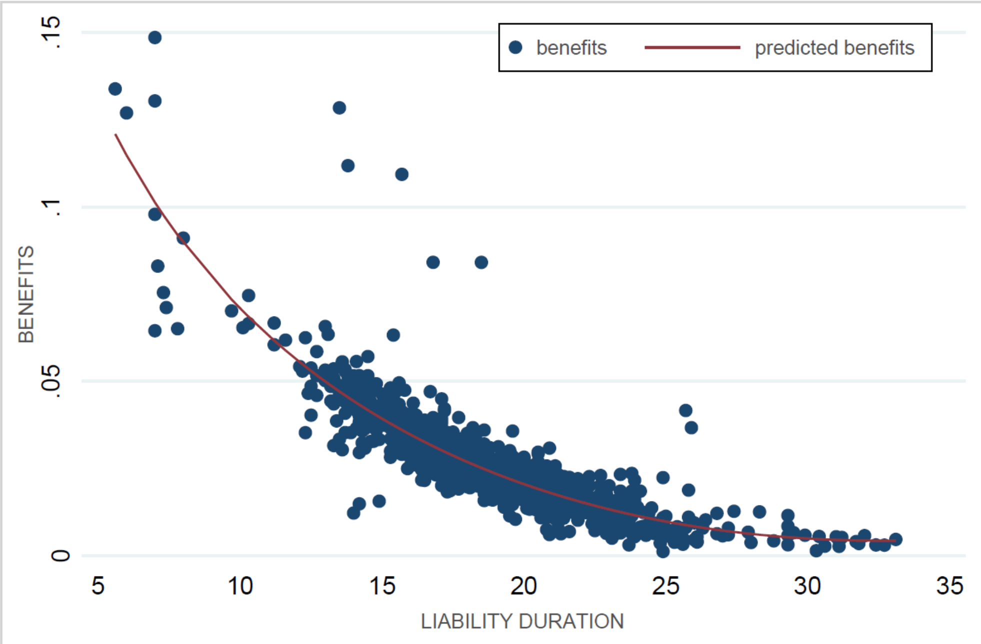

Figure 4: **Benefits as a function of the liability duration**
The dots in this figure show the observed ratios of pension payments to pension liabilities ($Benefits$) and the fitted curve for the observed ratios of pension payments to pension liabilities (red line), both as a function of the liability duration.

6 Illiquid assets allocation in different regulatory frameworks

Compared to banks and insurance companies, pension fund regulation is much more diverse across countries. Here, we focus on the difference in capital requirements for pension funds in the US and Canada to show our model implications outside the Netherlands. The US and Canada have fixed capital requirements, whereas the Netherlands has risk-based capital requirements.

Boon et al. (2018) study public, corporate, and industry wide pension funds in the US, Canada, and the Netherlands and find that the regulatory framework matters for the asset allocation decisions. They show that risk-based capital requirements and mark-to-market valuation are associated with a 7 percentage points lower risky asset exposure, regardless of market conditions. Given this evidence and the setup of our model we conjecture the following implications for the illiquid assets allocations in the US and in Canada. A higher interest rate risk exposure does not increase the capital requirements for pension funds in the US and Canada. Therefore, in absence of a risk-based capital requirement, the capital requirement as a function of the liability duration remains fixed. This implies that under these conditions the effect of the liability duration on the illiquid assets allocation is likely to be increasing. In other words, the younger the pension fund, the higher we expect the illiquid assets allocation to be. In these regulatory frameworks a longer liability duration creates opportunities to invest in illiquid assets. Therefore, we would expect higher illiquid asset allocations in the US and Canada. This is indeed what we observe empirically. The Willis Towers Watson Global Pension Assets Study (2018) shows that the value weighted average illiquid assets allocation in the US equals 28 percent and Canada equals 31 percent, whereas the value weighted average illiquid assets allocation in the Netherlands is only 17 percent.[18]

The predictions of our model are likely amplified when considering life insurers in the euro area. Life insurers also have long liability durations and are subject to Solvency II regulation in the euro area. The required capital under Solvency II is calculated such that the probability that the funding ratio falls below 100 percent on a one year horizon equals 0.5 percent. This implies that the capital requirement is more profound for life insurers than for pension funds. We would therefore predict the turning point of the hump-shaped effect of the liability duration on the illiquid assets allocation to be at a lower liability duration. In other words, the negative effect of having a higher liability duration (higher capital requirements) will outweigh the benefits (lower liquidity requirements) at a faster rate.

7 Conclusion

In this paper we study the impact of liquidity and capital requirements on pension fund's illiquid assets allocation. We use unique and proprietary data of Dutch defined benefit pension funds covering the period 2012-2017. Liquidity requirements result from short-term pension payments and collateral requirements on derivatives used for hedging purposes. In addition, Dutch defined benefit pension funds are capital constrained. They need to have sufficient capital to manage risks such as interest rate risk, market risk, currency risk and longevity risk. Capital is the surplus of the value of assets minus

[18]https://www.willistowerswatson.com/-/.../Global-Pension-Asset-Study-2018-Japan.pdf

the value of liabilities.

Liquidity and capital requirements interact. Fewer short-term pension liabilities, i.e., a longer liability duration, creates opportunities to invest in illiquid assets. However, a longer liability duration is associated with an increase in interest rate risk, which limits the opportunity to invest in illiquid assets due to a higher capital requirement. Furthermore, a pension fund can hedge certain risk exposures to reduce the capital requirement. This way hedging policies create opportunities to invest in illiquid assets. For instance, by hedging interest rate and currency risk, the pension fund is less exposed to these two risk factors and can take additional risk elsewhere before the capital requirement is binding. However, hedging strategies using derivatives involves collateral requirements. This hampers pension funds to invest in illiquid assets as they impose a liquidity requirement.

The key conclusions of our empirical analysis are as follows. First, we find a hump-shaped impact of liability duration on the fraction of risky assets allocated to illiquid assets. Up to 18 years, the liability duration positively affects this allocation. A higher liability duration means that a pension is less constrained by short-term pension payments. This creates opportunities to invest in illiquid assets. However, beyond this point, the effect is reversed and the allocation to illiquid assets decreases. The capital requirement becomes prominent as a result of high interest rate risk. Pension funds with high liability duration require capital to manage this risk, lowering opportunities to invest in illiquid assets.

Second, we do not find evidence that swap hedge ratios impact the illiquid assets allocation: the liquidity and capital requirements cancel out against each other. In case of currency risk hedging, however, hedging does impact the illiquid assets allocation positively. In line with the positive (less capital requirements) and negative (more liquidity needs) implications of hedging, currency risk hedging creates opportunities to take additional risks by investing in illiquid assets.

These findings offer important policy implications. It does not appear obvious for long term investors to automatically invest more in illiquid assets. The capital requirement for defined benefit pension funds becomes a binding constraint if the duration is substantially high. Although relaxing capital requirements for interest rate risk might seem a reasonable solution to mitigate the requirement, this is not what we recommend. The interest rate risk is inherent to the nature of the pension liabilities in a defined benefit pension contract.

If a pension fund offers guaranteed benefits the interest rate risk becomes one of the key risk factors to manage. The interest rate risk by definition increases for guarantees that stretch over a longer horizon. An alternative approach would be to redefine the nature of the liabilities such that they no longer embed long term interest rate guarantees. This however means that the interest rate risk is shifted to the pension fund's beneficiaries. Those beneficiaries should be able to understand and bear the increased risk.

Another policy implication concerns the importance of liquidity and collateral management for pension funds. Pension funds increasingly use derivatives to hedge risks. Although the exposure to interest rate risk and currency risk decrease through the application of derivatives, it also involves greater liquidity needs. Those liquidity needs can increase exponentially in times of market turbulence. Collateral management is key and becomes even greater once pension funds are integrated in central clearing of derivatives. Pension funds should prepare adequate contingency planning to be able to manage collateral through periods of market turbulence. More emphasis could be placed on liquidity and collateral management in pension regulation, as this is largely missing today.

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Table 2: **Total assets under management**

This table shows the total assets under management in billions of all pension funds (left column) and of the pension funds included in the analysis (right column) at the end of each year. The total number of pension funds in our sample is denoted by N. In the analysis, we leave out pension funds that are liquidated during the sample period.

year	**total AUM all**	**total AUM included**
2012	904.15	894.33
2013	945.98	936.50
2014	1131.74	1124.42
2015	1146.66	1118.72
2016	1262.54	1233.41
2017	1326.07	1297.67
N	330	219

Table 3: **Descriptive statistics**

Panel A provides summary statistics of pension funds' strategic asset allocation. The means and standard deviations of the actual asset allocation are shown between brackets. Panel B provides the summary statistics of the variables specified in Section 3: allocation to illiquid assets (w^{ILLIQ}), allocation to risky assets (w^{RISKY}), fraction of risky assets allocated to illiquid assets (w^{ILLIQ}/w^{RISKY}), liability duration (D_V), collateral requirements on interest rate derivatives (CRr), collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of investments outside euro area (w^{FX}), log of total AUM ($Size$), required funding ratio (Rfr), and one period lag of the actual funding ratio (Fr). The summary statistics are computed as the equally weighted average over all pension funds and all quarters in the 2012-2017 period.

Panel A: asset allocations	**mean**	**std. dev.**	**p10**	**p50**	**p90**	**obs.**
Liquid assets						
government bonds	0.33 [0.31]	0.20 [0.21]	0.05	0.33	0.60	4,956
stocks mature markets	0.29 [0.30]	0.13 [0.13]	0.16	0.27	0.43	4,956
credits	0.18 [0.19]	0.12 [0.11]	0.00	0.17	0.34	4,956
stocks emerging markets	0.05 [0.05]	0.04 [0.04]	0.00	0.05	0.10	4,956
inflation index-linked bonds	0.02 [0.02]	0.05 [0.05]	0.00	0.00	0.08	4,956
cash and short-term receivables	0.01 [0.03]	0.07 [0.08]	0.00	0.00	0.03	4,956
listed real estate	0.02 [0.03]	0.03 [0.04]	0.00	0.00	0.05	4,956
commodities	0.01 [0.01]	0.02 [0.02]	0.00	0.00	0.05	4,956
Illiquid assets						
non-listed real estate	0.04 [0.04]	0.05 [0.05]	0.00	0.03	0.12	4,956
mortgages	0.02 [0.02]	0.04 [0.04]	0.00	0.00	0.07	4,956
private equity	0.01 [0.01]	0.02 [0.02]	0.00	0.00	0.05	4,956
hedge funds	0.01 [0.01]	0.02 [0.02]	0.00	0.00	0.04	4,956

Panel B: variables	**mean**	**std. dev.**	**p10**	**p50**	**p90**	**obs.**
Allocation to illiquid assets	0.08	0.08	0.00	0.06	0.20	4,956
Allocation to risky assets	0.64	0.18	0.40	0.65	0.90	4,956
Fraction risky in illiquid assets	0.13	0.12	0.00	0.11	0.30	4,904
Liability duration	18.90	3.98	14.60	18.60	23.90	4,978
CR on interest rate derivatives	0.05	0.04	0.00	0.04	0.10	4,973
CR on currency derivatives	0.05	0.04	0.00	0.05	0.10	4,991
Bond hedge ratio	0.25	0.14	0.09	0.22	0.45	4,940
Foreign investments	0.22	0.22	0.00	0.20	0.51	3,682
Log of total AUM	5.84	0.81	5.00	5.79	6.86	4,997
Required funding ratio	1.16	0.07	1.10	1.16	1.23	4,992
Actual lagged funding ratio	1.09	0.13	0.96	1.07	1.22	4,992

Table 4: **Time variation strategic illiquid assets allocation**
This table shows the cross-sectional average time variation of pension fund's illiquid assets allocation over the period 2012–2017. The average time variation is computed as the cross-sectional average of the standard deviation of pension funds' strategic illiquid assets allocations over time.

	Average time variation
allocation to non-listed real estate	0.0146
allocation to mortgages	0.0153
allocation to private equity	0.0040
allocation to hedge funds	0.0048
allocation to illiquid assets	0.0251

Table 5: **Descriptive statistics split**

This table specifies the summary statistics of the variables specified in Section 3 for pension funds that *do invest in illiquid assets (Panel A) and pension funds that do not invest in illiquid assets (Panel B)*: allocation to illiquid assets (w^{ILLIQ}), allocation to risky assets (w^{RISKY}), fraction of risky assets allocated to illiquid assets (w^{ILLIQ}/w^{RISKY}), liability duration (D_V), collateral requirements on interest rate derivatives (CRr), collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of investments outside euro area (w^{FX}), log of total AUM ($Size$), required funding ratio (Rfr), and the one period lag of the actual funding ratio (Fr). The summary statistics are computed as the equally weighted average over all pension funds and all quarters in the 2012-2017 period.

Panel A: pension funds investing in illiquid assets

	mean	**std. dev.**	**p10**	**p50**	**p90**
Allocation to illiquid assets	0.12	0.08	0.03	0.11	0.22
Allocation to risky assets	0.67	0.16	0.47	0.67	0.90
Fraction risky in illiquid assets	0.18	0.10	0.05	0.16	0.32
Liability duration	18.61	3.50	15.00	18.00	23.00
CR on interest rate derivatives	0.05	0.04	0.00	0.04	0.09
CR on currency derivatives	0.06	0.04	0.00	0.05	0.10
Bond hedge ratio	0.24	0.12	0.10	0.22	0.40
Foreign investments	0.23	0.22	0.00	0.23	0.53
Log of total AUM	6.05	0.77	5.19	5.98	7.00
Required funding ratio	1.17	0.07	1.11	1.17	1.24
Actual lagged funding ratio	1.09	0.12	0.96	1.08	1.22

Panel B: pension funds not investing in illiquid assets

	mean	**std. dev.**	**p10**	**p50**	**p90**
Allocation to illiquid assets	0.00	0.00	0.00	0.00	0.00
Allocation to risky assets	0.57	0.22	0.30	0.56	0.91
Fraction risky in illiquid assets	0.00	0.00	0.00	0.00	0.00
Liability duration	20.00	4.88	14.00	20.00	26.00
CR on interest rate derivatives	0.05	0.05	0.00	0.05	0.12
CR on currency derivatives	0.04	0.04	0.00	0.03	0.09
Bond hedge ratio	0.28	0.18	0.08	0.23	0.58
Foreign investments	0.18	0.19	0.00	0.12	0.44
Log of total AUM	5.28	0.62	4.65	5.30	6.03
Required funding ratio	1.15	0.06	1.08	1.14	1.22
Actual lagged funding ratio	1.10	0.16	0.95	1.07	1.24

Table 6: **Correlation table of key variables**

This table provides the correlation matrix of the key variables: liability duration (D_V), collateral requirements on interest rate derivatives (CRr), collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of investments outside euro area (w^{FX}), log of total AUM ($Size$), pension fund type ($Type$), required funding ratio (Rfr), and the one period lag of the actual funding ratio (Fr).

Correlation matrix

	D_V	CRr	$CRfx$	ϕ^B	w^{FX}	$Size$	$Type$	Rfr	Fr
D_V	1								
CRr	0.40	1							
$CRfx$	0.02	0.12	1						
ϕ^B	−0.29	−0.40	−0.24	1					
w^{FX}	0.20	0.01	0.27	−0.17	1				
$Size$	0.04	0.06	0.21	−0.15	0.28	1			
$Type$	−0.28	−0.28	−0.05	0.25	−0.05	−0.44	1		
Rfr	0.12	−0.17	0.13	−0.24	0.29	0.16	−0.04	1	
Fr	−0.33	−0.19	−0.08	0.06	−0.07	−0.15	0.22	−0.02	1

Table 7: **Main results**

In this table, we show the random effects estimators based on the regression (15). The dependent variable in the first column is the fraction of risky assets allocated to illiquid assets (w^{ILLIQ}/w^{RISKY}), the dependent variable in the second column is the allocation to illiquid assets (w^{ILLIQ}) and the third column uses the risky assets allocation as dependent variable (w^{RISKY}). The independent variables include the liability duration (D_V), the liability duration squared (D_V^2), the collateral requirements on interest rate derivatives (CRr), the collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of foreign investments (w^{FX}), the log of total AUM ($Size$), $Corp$ indicates a corporate pension fund, $Prof$ indicates a professional pension fund, Rfr is the required funding ratio, and Fr the one period lag of the actual funding ratio. Standard errors are between parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1)	(2)	(3)
Dependent variable	w^{ILLIQ}/w^{RISKY}	w^{ILLIQ}	w^{RISKY}
D_V	.0254***	.0126***	−.0404***
	(0056)	(.0039)	(.0062)
D_V^2	−.0007***	−.0004***	.0009***
	(.0001)	(.0001)	(.0002)
CRr	−.0124	−.0141	−.0208
	(.0576)	(.0405)	(.0713)
$CRfx$	.1784***	.1371***	.4104***
	(.0363)	(.0255)	(.0481)
ϕ^B	.0204	−.0761***	−.4038***
	(.0181)	(.0127)	(.0220)
w^{FX}	−.0125	−.0013	−.1342***
	(.0125)	(.0088)	(.0152)
$Size$	.0736***	.0566***	.0604***
	(.0102)	(.0075)	(.0098)
$Corp$	−.0757***	−.0454***	.0218
	(.0217)	(.0143)	(.0194)
$Prof$	.0184	.0068	−.0234
	(.0438)	(.0288)	(.0380)
Rfr	−.0006	.0045	.0192
	(.0190)	(.0133)	(.0277)
Fr	−.0686**	−.0562***	−.0723**
	(.0275)	(.0192)	(.0304)
time FE	Y	Y	Y
N	3,401	3,401	3,433
left-censored	877	890	n/a
uncensored	2,524	2,511	n/a

Table 8: **Main results separate illiquid assets classes**

In this table, we show the random effects estimators based on the regression (15) *for separate illiquid asset classes*. The dependent variable in the first column is the fraction of risky assets allocated to real estate (w^{RE}/w^{RISKY}), in the second column the fraction of risky assets allocated to mortgages (w^{MG}/w^{RISKY}), in the third column the fraction of risky assets allocated to private equity (w^{PE}/w^{RISKY}), and in the fourth column the fraction of risky assets allocated to hedge funds (w^{HF}/w^{RISKY}). The independent variables include the liability duration (D_V), the liability duration squared (D_V^2), the collateral requirements on interest rate derivatives (CRr), the collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of foreign investments (w^{FX}), the log of total AUM ($Size$), $Corp$ indicates a corporate pension fund, $Prof$ indicates a professional pension fund, Rfr is the required funding ratio, and Fr the one period lag of the actual funding ratio. Standard errors are between parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1)	(2)	(3)	(4)
Dependent variable	w^{RE}/w^{RISKY}	w^{MG}/w^{RISKY}	w^{PE}/w^{RISKY}	w^{HF}/w^{RISKY}
D_V	.0138***	.0178**	.0076**	.0753***
	(.0045)	(.0070)	(.0036)	(.0088)
D_V^2	−.0004***	−.0004**	−.0002***	−.0022
	(.0001)	(.0002)	(.0001)	(.0002)
CRr	.0409	−.0453	.0585*	−.1474*
	(.0427)	(.0947)	(.0325)	(.0835)
$CRfx$	.1085***	.2535***	−.2068***	−.0216
	(.0316)	(.0420)	(.0435)	(.0653)
ϕ^B	.0187	.0151	−.0209**	−.0855***
	(.0143)	(.0281)	(.0102)	(.0243)
w^{FX}	.0767***	−.0454***	.0041	.0290*
	(.0101)	(.0172)	(.0069)	(.0164)
$Size$	.0541***	.0510***	.0608***	.0156
	(.0088)	(.0120)	(.0065)	(.0102)
$Corp$	−.0544***	−.0846***	−.0218**	.0068
	(.0175)	(.0223)	(.0091)	(.0178)
$Prof$	−.0004	−.0620	.0300*	.0937***
	(.0377)	(.0444)	(.0161)	(.0330)
Rfr	−.0001	−.2514***	.1340***	.0172
	(.0134)	(.0705)	(.0309)	(.0138)
Fr	−.1206***	.1164***	.0725***	−.1167
	(.0220)	(.0357)	(.0158)	(.0360)
time FE	Y	Y	Y	Y
N	3,432	3,432	3,432	3,432
left-censored	1,359	2,186	2,200	2,851
uncensored	2,073	1,246	1,232	581

Table 9: **Robustness - actual assets allocation**

In this table, we show the random effects estimators based on (15) *using the actual asset allocation.* The dependent variable in the first column is the fraction of risky assets allocated to illiquid assets (w^{ILLIQ}/w^{RISKY}), the dependent variable in the second column is the allocation to illiquid assets (w^{ILLIQ}) and the third column uses the risky assets allocation as dependent variable (w^{RISKY}). The independent variables include the liability duration (D_V), the liability duration squared (D_V^2), the collateral requirements on interest rate derivatives (CRr), the collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of foreign investments (w^{FX}), the log of total AUM ($Size$), $Corp$ indicates a corporate pension fund, $Prof$ indicates a professional pension fund, Rfr is the required funding ratio, and Fr the one period lag of the actual funding ratio. Standard errors are between parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1)	(2)	(3)
Dependent variable	w^{ILLIQ}/w^{RISKY}	w^{ILLIQ}	w^{RISKY}
D_V	.0120**	.0071**	−.0277***
	(0050)	(.0035)	(.0049)
D_V^2	−.0004***	-.0002***	.0006***
	(.0001)	(.0001)	(.0001)
CRr	.0355	.0397	.1221**
	(.0517)	(.0364)	(.0546)
$CRfx$	.0151	.0256	.2377
	(.0325)	(.0229)	(.0366)
ϕ^B	.0127	−.0194*	−.2342***
	(.0162)	(.0115)	(.0168)
w^{FX}	.0424***	.0144*	−.1334***
	(.0108)	(.0076)	(.0116)
$Size$	.0625***	.0486***	.0562***
	(.0093)	(.0064)	(.0087)
$Corp$	−.0535***	−.0351***	.0030
	(.0173)	(.0121)	(.0167)
$Prof$	.0053	.0051	−.0072
	(.0341)	(.0238)	(.0330)
Rfr	.0608***	.0601***	.0112
	(.0180)	(.0127)	(.0210)
Fr	−.1418***	−.1055***	−.0079
	(.0245)	(.0173)	(.0236)
time FE	Y	Y	Y
N	3,400	3,416	3,432
left-censored	606	667	n/a
uncensored	2,794	2,749	n/a

Table 10: **Robustness - alternative measure of liability duration**

In this table, we show the random effects estimators based on (15) *using an alternative measure for the liability duration.* The dependent variable in the first column is the fraction of risky assets allocated to illiquid assets (w^{ILLIQ}/w^{RISKY}), the dependent variable in the second column is the allocation to illiquid assets (w^{ILLIQ}) and the third column uses the risky assets allocation as dependent variable (w^{RISKY}). The independent variables include the ratio of pension payments to liabilities ($Benefits$), the ratio of pension payments to liabilities squared ($Benefits^2$), the collateral requirements on interest rate derivatives (CRr), the collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of foreign investments (w^{FX}), the log of total AUM ($Size$), $Corp$ indicates a corporate pension fund, $Prof$ indicates a professional pension fund, Rfr is the required funding ratio, and Fr the one period lag of the actual funding ratio. Standard errors are between parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1)	(2)	(3)
Dependent variable	w^{ILLIQ}/w^{RISKY}	w^{ILLIQ}	w^{RISKY}
$Benefits$	6.9264***	4.3555***	2.8844*
	(1.5747)	(1.0672)	(1.7548)
$Benefits^2$	−71.5539***	−38.0856**	12.4495
	(22.1661)	(15.0461)	(24.3063)
CRr	.0894	.0708	−.0512
	(.1408)	(.0964)	(.1830)
$CRfx$	.1016	.0875	.3857***
	(.0806)	(.0553)	(.1100)
ϕ^B	−.0767*	−.1045***	−.4227***
	(.0382)	(.0264)	(.0469)
w^{FX}	.0342	.0090	−.1412***
	(.0271)	(.0186)	(.0345)
$Size$	.0774***	.0543***	.0368***
	(.0125)	(.0083)	(.0131)
$Corp$	−.0760***	−.0466	.0069
	(.0216)	(.0142)	(.0227)
$Prof$	−.0026	−.0099	−.0485
	(.0415)	(.0272)	(.0431)
Rfr	.2196**	.2517***	.6764***
	(.1153)	(.0788)	(.1479)
Fr	−.0128	−.0406	−.1867***
	(.0513)	(.0349)	(.0576)
time FE	Y	Y	Y
N	700	700	707
left-censored	182	182	n/a
uncensored	518	518	n/a

Table 11: **Robustness - alternative measure collateral requirements**
In this table, we show the random effects estimators based on (15) *using an alternative measure for the collateral requirements.* The dependent variable in the first column is the fraction of risky assets allocated to illiquid assets (w^{ILLIQ}/w^{RISKY}), the dependent variable in the second column is the allocation to illiquid assets (w^{ILLIQ}) and the third column uses the risky assets allocation as dependent variable (w^{RISKY}). The independent variables include the liability duration (D_V), the liability duration squared (D_V^2), the collateral requirements on interest rate derivatives (CRr), the collateral requirements on currency derivatives ($CRfx$), bond hedge ratio (ϕ^B), fraction of foreign investments (w^{FX}), the log of total AUM ($Size$), $Corp$ indicates a corporate pension fund, $Prof$ indicates a professional pension fund, Rfr is the required funding ratio, and Fr the one period lag of the actual funding ratio. Standard errors are between parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

	(1)	(2)	(3)
Dependent variable	w^{ILLIQ}/w^{RISKY}	w^{ILLIQ}	w^{RISKY}
D_V	.0252***	.0125***	−.0403***
	(.0056)	(.0039)	(.0065)
D_V^2	−.0006***	−.0003***	.0009***
	(.0001)	(.0001)	(.0002)
CRr	.0670	.0495	.0204
	(.0816)	(.0573)	(.0939)
$CRfx$	.2407***	.1715***	.4096***
	(.0442)	(.0311)	(.0583)
ϕ^B	.0186	−.0746***	−.3963***
	(.0180)	(.0127)	(.0219)
w^{FX}	−.0143	.0002	−.1313***
	(.0125)	(.0088)	(.0151)
$Size$	.0745***	.0572***	.0678***
	(.0112)	(.0075)	(.0122)
$Corp$	−.0742***	−.0441***	.0288
	(.0218)	(.0144)	(.0236)
$Prof$	.0197	.0079	−.0179
	(.0440)	(.0290)	(.0469)
Rfr	.0012	.0059	.0085
	(.0190)	(.0133)	(.0273)
Fr	−.0685**	−.0567***	−.0829***
	(.0275)	(.0192)	(.0310)
time FE	Y	Y	Y
N	3,400	3,400	3,431
left-censored	877	890	n/a
uncensored	2,523	2,510	n/a