BANK OF ENGLAND

Staff Working Paper No. 757

What drives UK defined benefit pension funds' investment behaviour?

Graeme Douglas and Matt Roberts-Sklar

October 2018

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Abstract

We have developed a structural model to explain defined benefit (DB) pension funds' investment behaviour. The model is calibrated to the aggregate UK DB pension fund and four different cohorts of funds. We use the model to estimate how pension funds can be expected to adjust their asset portfolios in the face of different exogenous shocks. Our results suggest that pension funds are sensitive to shocks that change their funding ratios — that is, the ratio of pension assets to liabilities. Deteriorations in funding ratios encourage pension funds supported by financially weaker corporate sponsors to switch some equity holdings into bonds. This is because reduced funding ratios weigh on the perceived vulnerability of already weak corporate sponsors. But similar deteriorations in funding ratios encourage funds supported by financially stronger corporates to increase their equity holdings to benefit from their higher expected returns. In contrast, shocks that result in material improvements in funding ratios — for example, resulting from a large rise in interest rates — encourage all pension funds to increase their bond holdings to 'lock in' those improved positions.

Key words: Pension funds, procyclicality.

JEL classification: G23, G11.

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The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or its committees. We thank Sahil Nerala for his contributions to Section 3 of this paper. We wish to thank David Blake, Jethro Green, Ashok Gupta, Andrew Harley, Amy Lee, Ian Tonks, Simon Willes, Nick Vause and seminar participants at the Bank of England for their helpful comments.

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ISSN 1749-9135 (on-line)

Section 1: Introduction

Pension funds play an important role in the provision of market-based finance. In the UK, defined benefit (DB) pension funds hold around £1.5 trillion of financial assets (Pension Protection Fund (2017)). DB funds promise pension members predetermined income streams, which are typically indexed to inflation, in their retirements. To meet those future obligations, funds invest contributions that are made periodically by *corporate sponsors* – typically the employer of pension members – in financial assets. DB pension funds have long-term investment horizons and are often therefore considered 'buy-and-hold' investors.

Since the crisis, the low interest rate environment, together with other factors, has led to a deterioration in UK DB pension funds' funding ratios – these are, the ratios of their pension assets to liabilities. In particular, lower interest rates pushed up the present value of pension liabilities by more than the increase in pension assets leaving many schemes in deficit (Eich and Saleheen (2017)). In 2017, the funding ratio of the aggregate UK DB pension fund was only 90.5% (Pension Protection Fund (2017)); hence, the aggregate UK DB pension fund was in deficit.

Over the same period, DB pension funds have materially shifted their asset holdings from equities to bonds. Having held 61.1% of assets in equities and 28.3% in bonds pre-crisis, by 2017 these proportions changed to 29.0% and 55.7%, respectively (Pension Protection Fund (2017)). Given the size of their asset holdings, changes in pension funds' asset allocation can materially affect asset prices. We therefore want to explore how DB pension funds adjust their asset allocations in response to changes in financial market prices and other variables, including longevity expectations. Do funds sponsored by weaker corporates have different incentives to those sponsored by stronger sponsors?

To help answer these questions, we have developed a structural model of DB pension funds' asset allocations. We calibrate the model to the aggregate UK DB pension fund and four pension cohorts that vary according to the strength of their funding ratios and the financial strength of their corporate sponsors. Our model is a micro-founded, stochastic framework that recognises; (i) the *investment risk* associated with the returns on financial assets and changes in the present value of pension liabilities (due to changes in the discount rate); and (ii) *covenant risk* associated with the sponsors' ability to make pension contributions to close deficits as and when they arise. It draws on empirical work on pension fund asset allocation (e.g. Webb (2007), Raul (2009) and Blake et al (2017)), and builds on theoretical models of pension fund asset allocation (e.g. Dinenis and Scott (1993), McCarthy and Miles (2011), Sundaresan and Zapatero (1997), and Blake (2003)).

In our model, we assume that corporate sponsors have primary control over asset allocation decisions, choosing the optimal weights in equities and bonds to maximise the value of shareholder equity (as in Harrison and Sharpe (1983)). A higher weight in equities introduces a trade-off for the sponsor. On the one hand, it means a higher expected return on the pension fund's assets, so the sponsor expects to use less of its cashflow on pension fund contributions. This translates to higher shareholder value. On the other hand, a higher weight in equities makes the sponsor's cashflows more volatile, increasing the risk premium that investors apply when valuing the sponsor's equity. This lowers shareholder value.

Our model suggest sponsor strength is critical. *Deteriorations* in funding ratios encourage funds supported by financially *weaker* sponsors to switch some equity holdings into bonds. This is because reduced pension funding ratios weigh on the perceived vulnerability of already weak corporate sponsors. But similar *deteriorations* in funding ratios encourage funds supported by financially *stronger* corporates to increase their equity holdings to benefit from their higher expected returns.

In contrast, shocks that cause funding ratios to increase towards and beyond 100% (i.e. where pension funds are fully funded) encourage all types of pension cohort to 'lock in' their improved funding ratios. They look to do this by increasing their bond holdings to better hedge against movements in the values of their pension liabilities.

The findings from our model are relevant to financial stability policymakers concerned about the adverse effects of procyclical investment behaviour – that is, selling in response to price falls, and vice versa (Bank of England (2014)). For example, if interest rates were to rise materially from current low levels, likely causing pension funds' funding ratios to increase significantly, our model estimates that pension funds would support bond market liquidity by behaving countercyclically – that is, buying as bond prices fall. However, this support for bond market liquidity may prove limited due to the typically slow moving investment behaviour of pension funds.

The paper proceeds as follows. In **Section 2**, we discuss how our paper fits into the existing literature. **Section 3** then provides some institutional background to the DB pensions market. **Sections 4 and 5** then describe our modelling methodology and our data parameterisation and calibration processes, respectively. We then discuss our model results and conclude in **Sections 6 and 7**.

Section 2: Related literature[1]

The key question we address in our paper is pension funds' asset allocation choice between equities and bonds.

The institutional set up of DB pension funds, with their guaranteed liabilities, has taken the study of their portfolio allocation beyond the simple mean-variance utility asset allocation of Tobin (1958) and Markowitz (1952). A number of papers (e.g. Dinenis and Scott (1993), McCarthy and Miles (2011) and Sundaresan and Zapatero (1997)) have tried to model the portfolio allocation of pension funds taking into account the nature of their liabilities. And IMF (2017) discusses the risk-return trade-off for pension funds seeking to exit from funding deficits.

In our model, we examine the asset allocation decision from the perspective of the pension fund sponsor. Sharpe (1976) and Treynor (1977) showed that the contracts between sponsors and pension beneficiaries essentially represent put options owned by pension beneficiaries. These options are exercisable upon sponsor bankruptcy, and written on the assets of the pension fund with a strike price equal to the value of pension liabilities. Bodie (1990) also views pension obligations as a complex contingent claim on the sponsor, the value of which increases with the riskiness of pension fund assets. Harrison and Sharpe (1983) derive optimal funding and asset allocations based on sponsors' desire to maximise shareholder wealth. Blake (2003) outlines an asset-liability matching approach, whereby the sponsors' contribution rate is set to ensure the pension funds' expected funding surplus lies within a certain range, and the pension funds' asset allocations are set to ensure as little volatility in the surplus and contribution rate as possible.

Several papers explore the impact of pension fund risk on sponsor cost of capital and shareholder value. In their regression analysis of US pension funds, Jin, Merton and Bodie (2006) show that sponsors' own equity returns are affected by the risk from their corporate pension plans. Campbell, Dhaliwal and Schwartz (2012) find that an increase in mandatory pension contributions increases sponsors' cost of capital, but only for firms facing greater external financing constraints. Rauh (2006) finds that capital expenditure declines when corporate sponsors are required to make higher mandatory contributions to DB pension plans, even when controlling for correlations between changes in the pension funding ratio and the sponsor''s unobserved investment opportunities. Bunn et al (2018) find that corporate sponsors with larger pension deficits voluntarily pay lower dividends (but

[1] With particular thanks to David Blake and Ian Tonks for sharing their insights on the literature.

they do not invest less). More generally, Minton and Schrand (1999) find that cash flow volatility is associated with higher costs of accessing external capital.

In their simulations, Alderson and Seitz (2013) find that whilst a higher weight in equities increases the expected value of pension asset portfolios, thereby reducing the net cost of supporting the plan for the sponsor, it also makes the performance of the pension fund more correlated with the performance of the sponsor. This latter effect means the pension fund requires higher sponsor contributions at the very time that sponsor earnings fall. Webb (2007) indicates that, for pension funds in deficit, the incentives are for the corporate sponsors to move their asset allocations into equities in a 'gamble for redemption'. Rauh (2009) finds that pension schemes in deficit invest a greater percentage of their assets in safe investments (government bonds and cash), and better funded pension schemes invest a greater percentage in equities. Cocco and Volpin (2007) find evidence that firms who have a greater percentage of pension fund trustees who are insiders (with respect to the corporate sponsor) tend to invest a greater percentage of pension fund assets in equities.

In their empirical analysis of UK DB pension fund asset allocation, Blake et al (2017) find that pension funds tend to switch from equities to bonds as their liabilities mature. But in the short term, pension funds mechanically rebalance their portfolios to maintain target asset allocation weights.

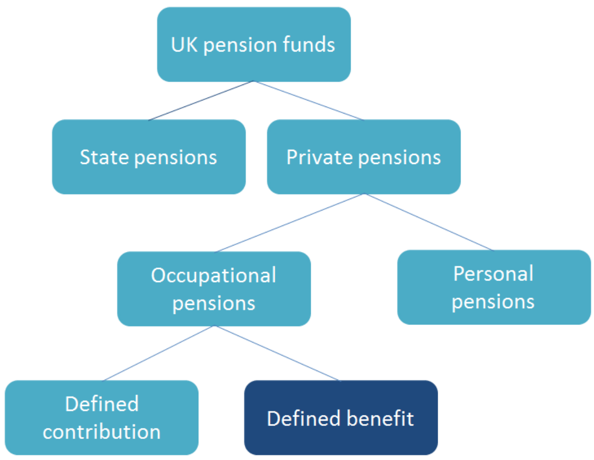
A key element of our model is covenant risk, i.e. the risk that the corporate sponsor fails and is unable to make the necessary contributions to close the pension fund deficit. Chen, Yu and Zhang (2013) incorporate sponsor bankruptcy risk into their analysis of pension funds. They hypothesise that firms with higher default risk have an incentive to 'gamble for redemption', investing in riskier assets.

Section 3: UK defined benefit pension funds

The model described in this paper examines the investment behaviour of UK DB pension funds. Such funds are a type of occupational pension fund – that is, those provided by corporates to their employees (**Figure 1**). DB pension funds promise pension members predetermined income streams (which are typically indexed to inflation) in their retirements. To meet those future obligations, pension funds invest contributions that are made periodically by corporates in financial assets. Defined benefit pension funds thus bear several types of risks, including:

- *Investment risk* associated with the uncertain returns from financial assets
- *Interest rate risk* associated with the rates at which pension liabilities are discounted when calculating their present values
- *Longevity risk* associated with pension members living longer than expected, which increases the number of years over which pension funds are required to make payments to members
- *Inflation risk* associated with the future values of the income streams promised to pension members.

Figure 1*: Stylised representation of the UK pension fund landscape*



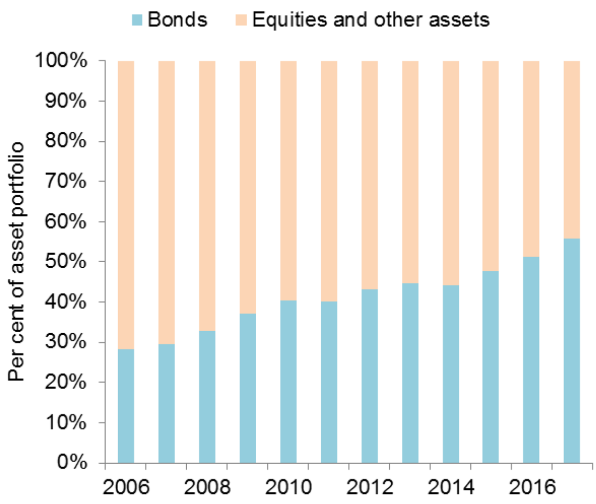
UK defined benefit pension funds are material investors in financial markets: in 2017, they held around £1.5 trillion of assets (Pension Protection Fund (2017)). Their asset allocation decisions are therefore important for financial stability. In particular, if they were to invest in a procyclical way – that is, sell as prices fall, and vice versa – they could amplify asset price swings.

A number of agents influence the asset allocation decisions of UK defined benefit pension schemes. A table in **Annex 1** summarises the roles of the key agents.

There has been a structural shift in pension funds' asset allocations in recent years. **Chart 1** shows that pension funds' proportional bond holdings has increased from 28.3% to 55.7% of total assets between 2006 and 2017, while proportional equity (and other asset) holdings reduced from 61.1% to 29.0% over the same period (Pension Protection Fund (2017)).

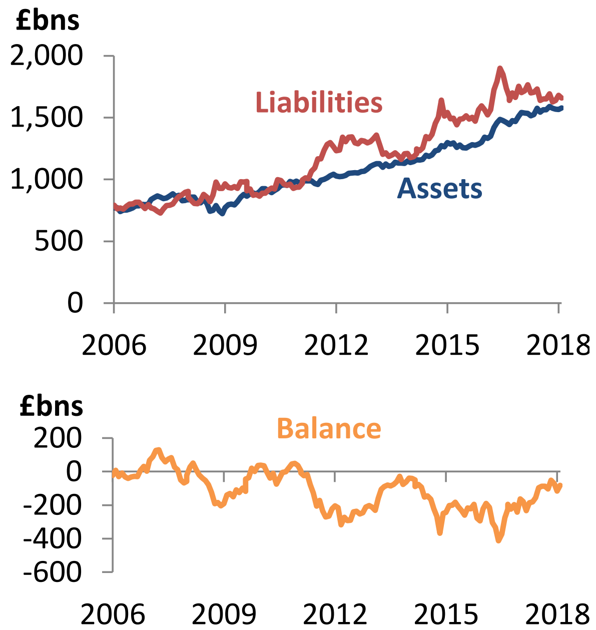
At the same time, there has been a deterioration in pension funding ratios: The aggregate UK pension funds' funding ratio deteriorated markedly between 2014 and 2017, as the value of pension liabilities increased faster than pension assets (**Chart 2**).

Chart 1: Asset allocation of the aggregate UK defined benefit pension fund



Source: Pension Protection Fund

Chart 2: Value of UK defined benefit pension funds' assets, liabilities and net balance



Source: Pension Protection Fund

Section 4: Model methodology

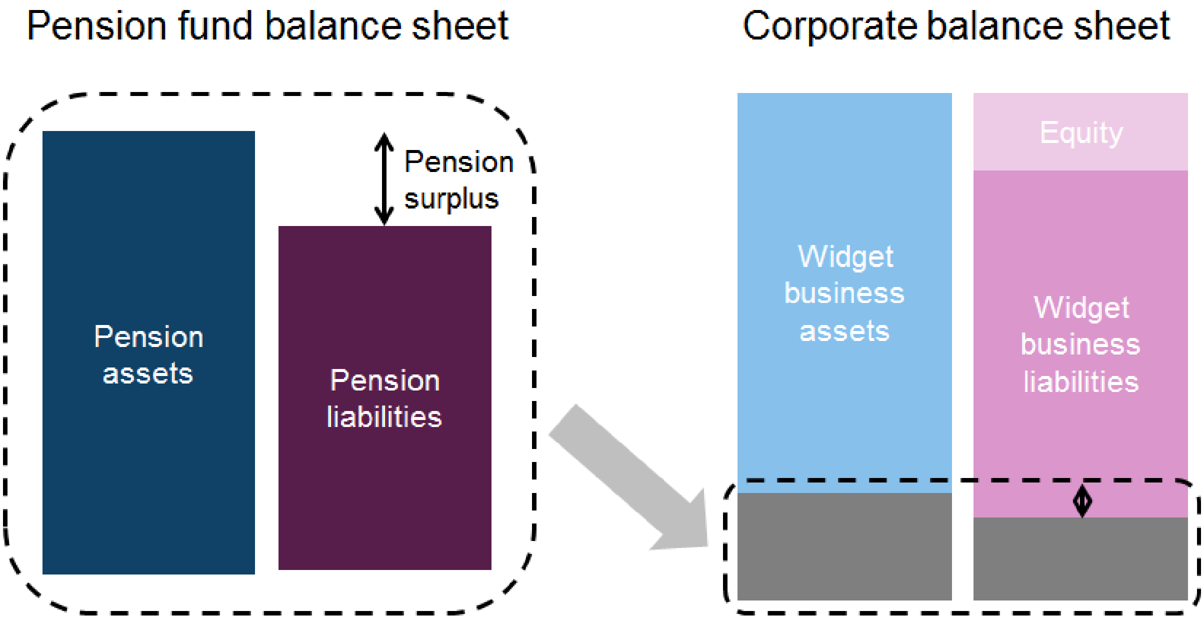
In this Section, we outline the modelling framework we have developed to assess the asset allocation decisions of UK DB pension funds.

Overarching model set-up

We employ a structural approach to modelling defined benefit pension funds that belong to UK private, non-financial corporations' (PNFCs) (adapting Merton's (1974) structural model, analogous to the model of UK life insurers in Douglas et al (2017)). That is, we develop representative balance sheets for UK PNFCs that incorporate financial assets held by, and pension liabilities owed by, their pension funds. We discuss model parameterisation and calibration in more detail in **Section 5**.

The set-up of these balance sheets is presented in a stylised way in **Figure 2**. The Figure demonstrates how the surplus (or deficit) of pension funds impacts corporates' broader balance sheets. In particular, and as we explain later in this Section, our model allows us to estimate the impact of the pension funds' asset allocations on corporates' expected future profits, and therefore on today's shareholder value or share price. It can therefore be used to understand how corporates would like to adjust pension funds' asset allocations in the face of different types of exogenous shocks.

***Figure 2**: Stylised representation of defined benefit pension fund sitting on balance sheet of private non-financial corporate (PNFC)*



Our model introduces two key sources of stochasticity:

1) **Investment risk** associated with the returns on financial assets, which impacts the values of the pension funds' assets and liabilities (due to changes in the discount rate), and therefore the pension deficit;
2) **Covenant risk** associated with the earnings from the corporates' widget business (that is, their non-pensions business), and therefore the sponsors' ability to make pension contributions to close deficits as and when they arise.

The balance sheets of the pension funds and the broader corporates are assumed to evolve to reflect changes in these two sources of uncertainty, together with the deterministic passage of time. Further, we assume that corporates can forecast the dynamics of their balance sheets.

In particular, for a given asset portfolio choice in the pension fund, the corporates can calculate the value of shareholder equity under this structural modelling framework. As we discuss later in this Section, this means that the corporates are able to choose the optimal asset portfolio in the pension fund that maximises shareholder equity. We then use this framework to estimate how corporates would be expected to adjust the asset portfolios of their pension funds in the face of different types of exogenous shocks.[2] These asset allocation adjustments are assumed to occur immediately after the introduction of exogenous shocks (i.e. at time zero).

[2] Another alternative specification would be to focus on the incentives of the boards of pension trustees, which represent pension members and seek to ensure that they receive what is owed to them. For example, McKillop and Poque (2010) find evidence of potential conflicts of interest between sponsors and trustees. As trustees are

In this model, we abstract from the actual mechanics of asset allocation decisions in pension funds, including the role of trustees (see **Section 7** for a further description). But we do incorporate some of the key features of regulation that apply to UK pension funds. In particular, as discussed further below, we use pensions data to calibrate: (i) the discount rate used to calculate the present value of pension liabilities; and (ii the time horizon over which sponsors are required to make contributions towards pension funds to close pension deficits.

We next discuss how we model the pension fund and broader corporate balance sheet, and then turn to the optimisation function that is assumed to inform the pension funds' investment behaviour.

Pension fund balance sheet

Pension fund assets and interest rates

For simplicity, we assume that the pension fund's asset portfolio, A, consists of two types of assets: equities, A^E, and bonds, A^B (which is assumed to be a mix of corporate and government bonds). As discussed in Section 3, bonds and equities account for the majority of aggregate UK defined benefit pension assets.

For equity, we assume that its value follows a Geometric Brownian Motion (GBM). In particular, it is assumed to grow on average at a rate determined by the sum of the risk-free rate, r_t^f, and a risk premium, ξ^E. But growth in the equity value also has a stochastic component, with shocks, dz_t^E, that follow a standard normal distribution scaled by an ex-ante, time-varying parameter, σ_t^E; that is:

$$\frac{dA_t^E}{A_t^E} = \left(r_t^f + \xi^E\right)dt + \sigma_t^E dz_t^E.$$

We assume that the volatility of equity, σ_t^E, reverts deterministically towards its long-run average, β^E, at a given speed, α^E.

$$d\sigma_t^E = \alpha^E(\beta^E - \sigma_t^E)dt.$$

We assume that the risk-free rate follows a one-factor Vasicek process (Vasicek (1977)) with a time-independent mean, β^{r_f}, a given speed of reversion, α^{r_f}, and stochastic shocks that follow a normal distribution scaled by a fixed parameter, σ^{r_f}:

$$dr_t^f = \alpha^{r_f}\left(\beta^{r_f} - r_t^f\right)dt + \sigma^{r_f} dz_t^{r_f}.$$

For bonds, we assume that its value follows the weighted average of two GBM processes: one describing the dynamics of the government bond price and one for the corporate bond price.

For the government bond GBM, the price is assumed to grow on average at a rate equal to the risk-free rate, r^f. But growth is subject to changes in the risk-free rate, which we translate into movements in the government bond price using proxies for the bond's duration, $(T-t)$, and convexity, $\frac{1}{2}(T-t)^2$:

$$\frac{dA_t^{GB}}{A_t^{GB}} = r_t^f dt - (T-t)dr_t^f - \frac{1}{2}(T-t)^2\left(dr_t^f\right)^2.$$

Similarly, under the corporate bond GBM, the price is assumed to grow on average at a rate equal to the sum of the risk-free rate, r^f, and a spread (or risk premium), ξ^{CB}. But growth is subject to changes in the risk-free rate and the risk premium, which we translate into movements in the corporate bond price using the same process as for the government bond price above:

likely to be risk averse – or possibly loss averse – however, it is difficult to specify and calibrate their optimisation function with any certainty.

$$\frac{dA_t^{CB}}{A_t^{CB}} = \left(r_t^f + \xi_t^{CB}\right)dt - (T-t)\left(dr_t^f + d\xi_t^{CB}\right) - \frac{1}{2}(T-t)^2\left(dr_t^f + d\xi_t^{CB}\right)^2.$$

We assume that the corporate bond spread follows a one-factor Vasicek process with a time-independent mean, $\beta^{\xi^{CB}}$, a given speed of reversion, $\alpha^{\xi^{CB}}$, and stochastic shocks that follow a normal distribution scaled by a fixed parameter, $\sigma^{\xi^{CB}}$. And noting the empirical relationship between corporate bond spreads and equity prices, we set the stochastic shocks equal to the weighted average of the stochastic shock for equity prices and an additional, independent stochastic shock. The weights for the two sources of shocks are determined by the historical correlation between the return on equities and changes in corporate bond spreads, $\rho^{E,\xi^{CB}}$:

$$d\xi_t^B = \alpha^{\xi^{CB}}\left(\beta^{\xi^{CB}} - \xi_t^{CB}\right)dt + \sigma^{\xi^{CB}}\left\{\rho^{E,\xi^{CB}}dz_t^E + \left(1 - \left(\rho^{E,\xi^{CB}}\right)^2\right)^{\frac{1}{2}}dz_t^{r_f}\right\}.$$

Given the above processes for government and corporate bonds, the pension fund's bond portfolio, A^B, adopts the following process:

$$\begin{aligned}\frac{dA_t^B}{A_t^B} &= w^{GB}\left\{r_t^f dt - (T-t)dr_t^f - \frac{1}{2}(T-t)^2\left(dr_t^f\right)^2\right\} \\ &\quad + (1-w^{GB})\left\{\left(r_t^f + \xi_t^{CB}\right)dt - (T-t)\left(dr_t^f + d\xi_t^{CB}\right) - \frac{1}{2}(T-t)^2\left(dr_t^f + d\xi_t^{CB}\right)^2\right\}.\end{aligned}$$

where the weighting on the government bond, w^{GB}, is set as a constant and equal to the proportion of all bond holdings accounted for by government bonds (i.e. we do not model the dynamics of w^{GB}).

For the total asset portfolio, we assume that its value follows the weighted average of the processes for equity and bonds, described above. However, at the end of each period, we allow for the possibility that the corporate sponsor contributes additional funds, ω_t^{Actual}, into the asset portfolio to plug deficits as and when they arise. We discuss the calculation of these periodic contributions later in this Section.

Upon receipt of these additional funds, the pension fund is assumed to invest in further equity and bonds in proportion to its current holdings of each. Hence, the process for the total asset portfolio is as follows:

$$\begin{aligned}\frac{dA_t}{A_t} &= w_t^E\left\{\left(r_t^f + \xi^E\right)dt + \sigma_t^E dz_t^E + \omega_t^{Actual}\right\} \\ &\quad + (1-w_t^E)\left\{w_t^{GB}\left(r_t^f dt - (T-t)dr_t^f - \frac{1}{2}(T-t)^2\left(dr_t^f\right)^2\right)\right. \\ &\quad \left. + (1-w_t^{GB})\left(\left(r_t^f + \xi_t^{CB}\right)dt - (T-t)\left(dr_t^f + d\xi_t^{CB}\right) - \frac{1}{2}(T-t)^2\left(dr_t^f + d\xi_t^{CB}\right)^2\right) + \omega_t^{Actual}\right\}.\end{aligned}$$

where

$$w_t^E = \frac{A_t^E}{A_t}.$$

<u>Pension fund liabilities</u>

Pension fund liabilities are assumed to consist solely of pension obligations to households. In practice, these obligations represent the promise to pay streams of income to pension holders in their retirement until their death, introducing uncertainty around the future size and timing of pension obligations. For simplicity however, we assume that the pension fund has a single, fixed pension obligation, L^{FV}, due in T years' time.

The present value of this pension obligation is determined by discounting it back to time t. Following UK pensions regulations, the relevant discount rate is assumed equal to the sum of the risk-free rate, r_t^f, and a time-independent liability risk premium, ξ^L.[3]

The value of the pension liability therefore changes with time (as time converges to maturity) and with changes in the risk-free rate, which cause the future liability to be discounted more or less heavily. Hence, the value of the pension liability at time t is:

$$L_t = \exp\left\{-(T-t)\left(r_t^f + \xi^L\right)\right\} L^{FV}.$$

Pension surplus (or deficit)

As is typical practice under UK pensions regulation, we define the pension surplus as the difference between the values of the pension assets and liabilities:

$$S_t = A_t - L_t.$$

As we explain later in this Section, if the pension fund has a negative pension surplus – that is, it has a pension deficit – the corporate sponsor is required make periodic pension contributions to close the deficit.

Corporate earnings

As explained in Figure 3, the pension fund constitutes a portion of the corporate sponsor's balance sheet. The remainder of the corporate balance sheet is dedicated towards the corporate's non-pension business (the 'widget business').

The corporate accrues income from the assets in the widget business and makes outgoing payments associated with its liabilities. And the difference between this income and outgoings (for non-debt holdings) provides us with a measure of the corporate's net earnings (e.g. earnings before interest and tax (EBIT)) from its widget business. This measure of net earnings represents an upper bound on the amount the corporate – in the face of a deficit in its pension fund – could contribute towards the pension fund in a given period.

We assume that the value of the corporate's net earnings, π_t, follows a Brownian Motion (BM). In particular, it is assumed to increase on average at a rate determined by the sum of the risk-free rate, r_t^f, and a risk premium, ξ^π. But this average increase is subject to a stochastic component, with shocks that follow a standard normal distribution scaled by an ex-ante, fixed parameter, σ^π. And noting the empirical relationship between corporate earnings and equity prices, we set the stochastic shocks equal to the weighted average of the stochastic shock for equity prices, dz^E, and an additional, independent stochastic shock, dz^π. The weights for the two sources of shocks are determined by the historical correlation between the return on equities and changes in corporate earnings, $\rho^{E,\pi}$:

$$d\pi_t = \left(r_t^f + \xi^\pi\right)dt + \sigma^\pi\left\{\rho^{E,\pi} dz_t^E + (1 - (\rho^{E,\pi})^2)^{\frac{1}{2}} dz_t^\pi\right\}.$$

Corporate contributions to pension fund

The pension fund sits on the corporate's balance sheet, which means that the corporate is liable for the pension liabilities in instances where the value of pension assets proves insufficient. Under UK

[3] In our model, pension liabilities are valued as 'technical provisions'. That is, pension funds apply their own judgement (which is influenced by actuarial trustees) around the appropriate risk premium to apply when calculating the present value of their liabilities. The risk premium typically depends on a number of variables, including the composition of pension funds' asset portfolios.

pensions regulations, in the face of a pension deficit, the corporate is therefore required to make periodic contributions in order to close the pension deficit over a given period of time.

Further, as pension deficits are recalculated infrequently, there is often a lag between a change in the pension deficit and the recalculation of the required contributions. In our model, **required contributions** by the corporate sponsor at time t, $\omega_t^{Required}$, therefore depend on the deficit in the previous period, $-S_{t-1}$, and the time period over which the deficit must be closed, $\tau^{Contributions}$:

$$\omega_t^{Required} = \frac{\max(-S_{t-1},\ 0)}{\tau^{Contributions}} = \frac{\max(-(A_{t-1} - L_{t-1}),\ 0)}{\tau^{Contributions}}.$$

Faced with a given level of *required* contributions, the *actual* level of contributions made by the corporate will depend on the value of its earnings. In particular, the corporate is assumed to contribute no more than its net earnings in that period. Additionally, due to UK pensions regulations, the corporate is only able to make positive contributions in any given period; that is, it is unable to withdraw funds from the pension fund.

Hence, **actual contributions** are as follows:

$$\omega_t^{Actual} = max(0, min(\omega_t^{Required}, \pi_t)).$$

Further, we also allow for the possibility of **corporate default**. This reflects instances where the corporate's earnings are insufficient to meet required interest payments on financial debt. In the model, we introduce a default indicator, whose value equals 1 in the situation where the corporate's net earnings are less than zero today or in any previous period, and equals zero otherwise:

$$I_t^{Default} = \begin{Bmatrix} 1 & if\ \pi_s < 0, \quad s \in \{0,1,\dots,t\} \\ 0 & otherwise \end{Bmatrix}.$$

Following a default event, we assume that the sponsor is unable to make any further contributions to the pension fund.

<u>Corporate objective function</u>

The corporate sponsor in our model is a publicly listed company, which exists to maximise value on behalf of its shareholders. We therefore assume that, at the start of the model (i.e. at time zero), the corporate seeks to maximise its share price, $Equity_0^{Corp}$, which we set equal to the present discounted value of all future free cash flows:

$$Equity_0^{Corp} = \sum_{t=1}^{T} \frac{FCF_t}{(1 + r_t^f + \xi^{Corp})^t} = \sum_{t=1}^{T} \frac{\pi_t - Interest - \omega_t^{Actual}}{(1 + r_t^f + \xi^{Corp})^t}.$$

In particular, we set the corporate's free cash flows, FCF_t, in a given period equal to its net earnings from the widget business (i.e. EBIT before pension contributions) minus any pension contributions, ω_t^{Actual} or debt interest payments, $Interest$ (which for simplicity we set to zero). And we set the discount rate of the corporate's equity equal to the sum of the risk-free rate, r_t^f, and a time-independent equity risk premium, ξ^{Corp}.

The equity risk premium reflects the compensation that risk averse investors demand for investing in a financial security that offers uncertain and therefore volatile returns (see e.g. Dison and Rattan (2017)). We assume that it is calculated as a weighted average of the risk associated with its pension fund and widget business. And we proxy for these weightings by comparing the size of the corporate's required pension contributions and its net earnings from the widget business at time zero.

$$\xi^{Corp} = \left(\frac{\omega_0^{Required}}{\pi_0}\right)\xi^{PF} + \left(1 - \frac{\omega_0^{Required}}{\pi_0}\right)\xi^{Widget}.$$

We calculate the risk associated with the pension fund by taking a weighted average of risk premiums of the pension fund's two asset holdings: equity and bonds.

$$\xi^{PF} = w^E \xi_0^E + (1 - w^E)\xi_0^B.$$

And, as discussed later in Section 5, **we calibrate the model using the risk premium that investors demand for investing in the corporate's widget business, ξ^{Widget}**.

As stated above, the corporate seeks to maximise its share price. And it is assumed to do this by choosing the optimal asset mix in the pension fund. As there are assumed to be two assets held by the pension fund, this amounts to it deciding on its optimal weight in equity, w^E.

$$\max_{w_E} \quad Equity_0^{Corp} = \sum_{t=1}^{T} \frac{\pi_t - Interest_t - \omega_t^{Actual}}{(1 + r_t^f + \xi^{Corp})^t}$$

The composition of the pension fund's asset portfolio therefore impacts the corporate sponsor's share value through two competing channels.

First, the asset mix of the pension fund impacts the corporate's **required pension contributions**. Equity has a higher expected return than bonds. So a higher weight in equity means that the pension fund is expected to have fewer and less frequent deficits. This means that the corporate expects to make fewer contributions to the pension fund over time, which positively affects the corporate's share price.

Second, the asset mix of the pension fund impacts the **risk premium** that investors demand in order to invest in the corporate's equity. Bonds typically entail a lower risk premium than equities, as their cash flows are more predictable. So a higher weight in equity means that investors discount the corporate's future free cash flows at a higher rate, which negatively impacts its share price.

These competing channels create a trade-off for the corporate sponsor. We discuss this further in **Section 6**.

Section 5: Data

To make our model a more realistic description of UK defined benefit pension fund asset allocation, we use data to: i) set some model parameters to observed values; and ii) calibrate an unobserved 'free' parameter.

Parameterisation

Our model includes numerous parameters whose values we determine exogenously. We parameterise the balance sheets of UK corporates which have defined benefit pension funds by combining together corporate data, sourced from Bureau van Dijk, with pension data, provided by the UK regulator of pension funds, 'the Pensions Regulator' (tPR). We conduct this data matching at the level of individual firms, which means that we are able to aggregate the data freely. All corporate and pensions data is taken from end-March 2016.[4]

In this paper, we aggregate our firm-level data in two ways. First, we combine the balance sheets of all firms in our population to produce the balance sheet of the aggregate UK defined benefit pension

[4] Where data points were unavailable for end-March 2016, we used the latest data points before then.

fund and the aggregate corporate sponsoring this fund. Second, we combine the balance sheets of firms with particular characteristics to produce cohorts of different fund types. In particular, we consider pension funds along two dimensions:

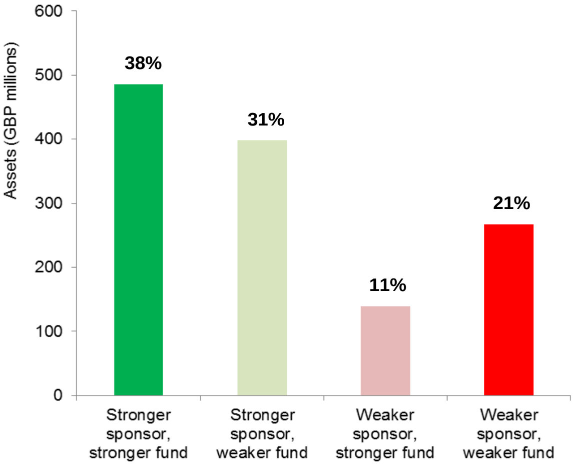
- **The pension funds' 'funding ratio'** – that is, the ratio of the value of their assets to the value of their liabilities. We define pension funds with funding levels of 80% or below as 'weaker funds', and those with higher funding levels as 'stronger funds'.
- **The 'financial strength' of the corporate sponsors**. We define corporates with debt interest coverage ratios – that is, the ratio of their 'earnings before interest and tax' (EBIT) to their debt interest expenses – of below 2 as 'weaker sponsors' and those above 2 as 'stronger sponsors'.

Applying these definitions to our population of UK corporates with defined benefit pension funds, we create four cohorts (**Table 1**). The value of the assets held by the two cohorts of pension funds supported by strong sponsors represents around 70% of the UK defined pensions sector; but the tail of 'weaker funds', particularly those supported by 'weaker sponsors', is material (**Chart 3**).[5]

Table 1*: Our four cohorts of pension funds*[6]

		'Financial strength' of corporate sponsor	
		Stronger	Weaker
'Funding ratio' of pension fund	Stronger	Stronger sponsor, stronger fund	Weaker sponsor, stronger fund
	Weaker	Stronger sponsor, weaker fund	Weaker sponsor, weaker fund

Chart 3*: Value of assets held by each pension cohort*



Source: Pension Protection Fund and Bureau van Dijk

For the dynamics of asset price processes, we use historical asset price data to parameterise the exogenous variables. We use financial asset price data up to and including end-March 2016 (as with the corporate and pensions data used to parameterise our agents' balance sheets). The values we have attached to the exogenous variables in our model are outlined in a summary table in **Annex 2**.

Calibration

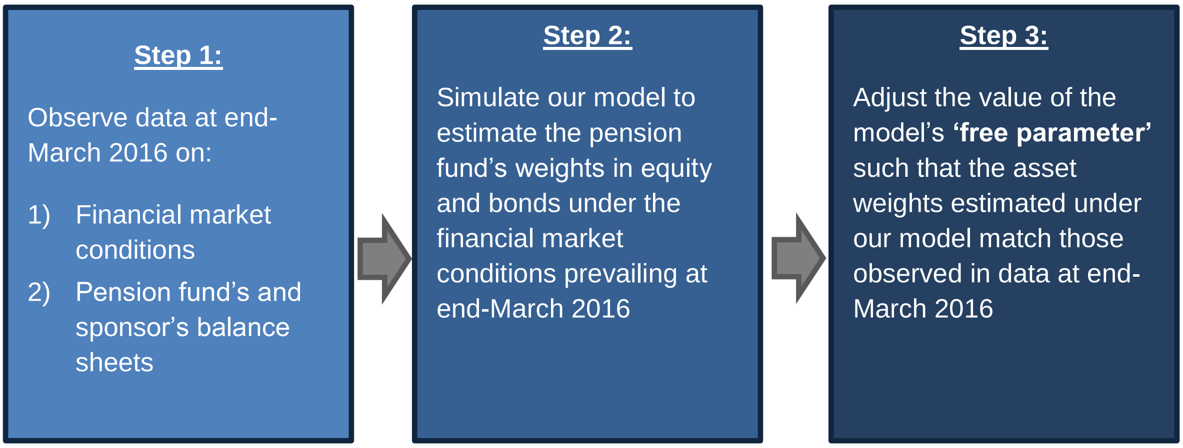
We aim to calibrate our model to real world data. In particular, the key output of our model is to estimate corporate sponsors' chosen asset allocations (i.e. their weights in equity and bonds) in the face of any given financial market conditions (e.g. the values of the risk-free rate, equity prices etc.). And in UK data, we can observe pension funds' asset allocations under the financial market conditions prevailing at end-March 2016. Our calibration process is to adjust the value of the model's 'free parameter' such that our model's estimation of the corporates' preferred asset allocation matches the asset allocation that we observe in data at end-March 2016. This calibration process is described in **Figure 3**.

The 'free parameter' that we use to calibrate the model is the risk premium that equity investors demand to invest in a sponsor's widget business, ξ^{Widget}, which is not observable in financial market

[5] Each pension fund cohort has an asset portfolio that is parameterised using regulatory data from the PPF/tPR.
[6] By pension 'cohorts', we mean different combinations of pension funds and sponsors. This compares to the typical use of the term 'cohorts' for pension funds, which refers to different age generations of pension members.

data.[7] This parameter affects the risk premium that investors demand for investing in the corporate's business as a whole:[8]

Figure 3: Illustration of model calibration process



$$\xi^{Corp} = \left(\frac{\omega_0^{Required}}{\pi_0}\right)\xi^{PF} + \left(1 - \frac{\omega_0^{Required}}{\pi_0}\right)\xi^{Widget}.$$

By affecting the risk premium that investors demand for investing in the corporate, changes in the value of the free parameter impact the corporate's trade-off between holdings of equities and bonds. In **Table 2**, we provide our model calibration results.

The calibration results indicate, as might be expected, that corporate sponsors defined as 'weaker' (i.e. those with debt interest coverage ratios of two or below) have the highest risk premia associated with their widget businesses. Perhaps less intuitively, we estimate that the aggregate sponsor has a lower risk premium than the corporate sponsors defined as 'stronger'. This latter finding could be attributed to some of the design choices imposed on our model.[9]

Table 2: Model calibration results

	Aggregate fund	**Stronger sponsor, stronger fund**	**Stronger sponsor, weaker fund**	**Weaker sponsor, stronger fund**	**Weaker sponsor, weaker fund**
Risk premium for the corporate's widget business	0.0390	0.1320	0.1560	0.2680	0.2340

Source: Model outputs

[7] Whilst we can estimate the risk premium that equity investors demand to invest in the corporate's equity, this risk premium compensates investors for risks associated with both the corporate's widget business (i.e. its non-pensions business) and its pension fund. That is, we are unable to isolate the risk premium that compensates solely for the corporate's widget business.
[8] As discussed in **Section 4**, we calculate the value of the risk premium that equity investors demand to invest in a sponsor's pension fund by taking a weighted average of risk premiums of the pension fund's two asset holdings: equity and bonds.
[9] For example, we model the dynamics of corporates' earnings using Brownian Motion (BM) processes. Such processes allow for the possibility that earnings can become negative (as opposed to Geometric Brownian Motion processes). But under BM processes, funds that have higher initial earnings (e.g. the aggregate sponsor) are less likely to experience negative earnings.

Section 6: Results

We use our structural model to estimate how pension funds may adjust their asset allocations in the face of different shocks. In particular, we focus on shocks to the values of three exogenous variables: (i) risk-free rates; (ii) equity prices; and (iii) longevity expectations. Shocks to these exogenous variables affect pension funds' funding ratios – that is, the ratio of the value of the pension funds' assets to their liabilities. And because corporate sponsors make contributions to plug pension deficits as and when they arise, these shocks also therefore impact the financial strength of the pension funds' corporate sponsors.

The time horizon over which these exogenous shocks are assumed to unfold, and pension funds are assumed to adjust their asset allocations in response, is around six months. This horizon reflects the time that may be required for pension funds to make agreements to adjust their asset allocations (e.g. to hold meetings with key decision makers).

We describe the results for each of these exogenous shocks below, focusing in particular on differences on expected investment responses across the cohorts of different fund types.

Shock to risk-free rates

We simulate exogenous shocks to risk-free rates, which we model as parallel shifts in the yield curve. Changes in risk-free rates are important to pension funds as they impact the values of both their assets and liabilities (which are discounted with reference to the risk-free rate). Hence, pension funds' 'funding ratios' tend to be sensitive to changes in risk-free rates. We examine the impact of decreases and increases in risk-free rates separately.

Falls in rates

Falls in the risk-free rate tend to result in deteriorations in pension funds' funding ratios. This is because long-dated pension liabilities increase in value by more than shorter-dated pension assets. The fall in funding ratios gives rise to two competing incentives:

1) ***'Expected pension contributions' channel***: As funding levels fall, corporate sponsors expect, all else equal, to make larger annual pension contributions over time. This encourages pension funds to switch some holdings of bonds to equities, which offer higher expected returns.
2) ***'Sponsor vulnerability' channel:*** Falls in the funding levels of pension funds weigh on the perceived riskiness of their corporate sponsors.[10] As a result, equity holders increase the risk premia they demand in order to continue investing in corporates' equity. This encourages pension funds to switch some holdings of equities to bonds to reduce to perceived riskiness of the corporates.

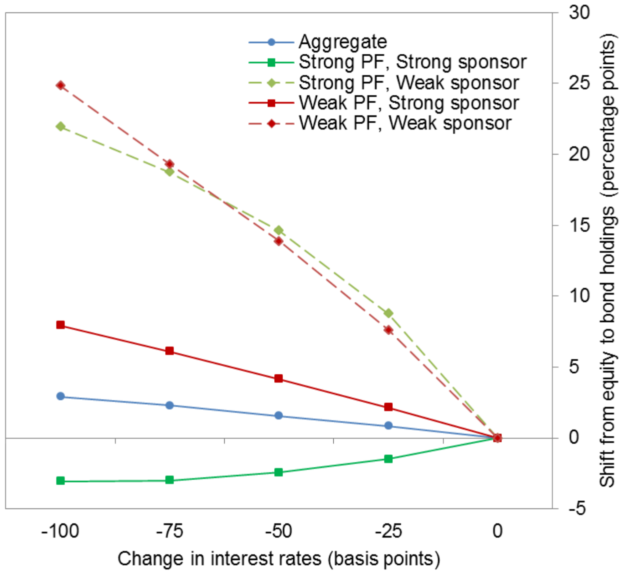
Chart 4 shows our model estimates for how pension funds are expected to adjust their bond holdings (by reducing their equity holdings) in the face of exogenous falls in the risk-free rate. The net outcome of the competing incentives discussed above varies across cohorts.

For the two pension cohorts supported by stronger sponsors, these incentives roughly balance out. This means that they are expected to behave broadly acyclically in bond markets – that is, they merely sit on their holdings in the face of falling interest rates (i.e. rising bond prices). In contrast, for the two pension cohorts supported by weaker sponsors, the incentive to switch into bonds in the face of higher perceived risks for the corporate dominates. Hence, these two pension cohorts are expected

[10] This effect may be partially offset by the mechanical fall in corporates' cost of capital (that is, the cost of funding their businesses), which arises from a fall in the risk-free rate. We ignore this possibility in our model.

to invest procyclically in bond markets – that is, increase their holdings as prices increase (due to falling risk-free rates).

***Chart 4**: Estimated change in pension funds' bond holdings for given basis points falls in risk-free rates*



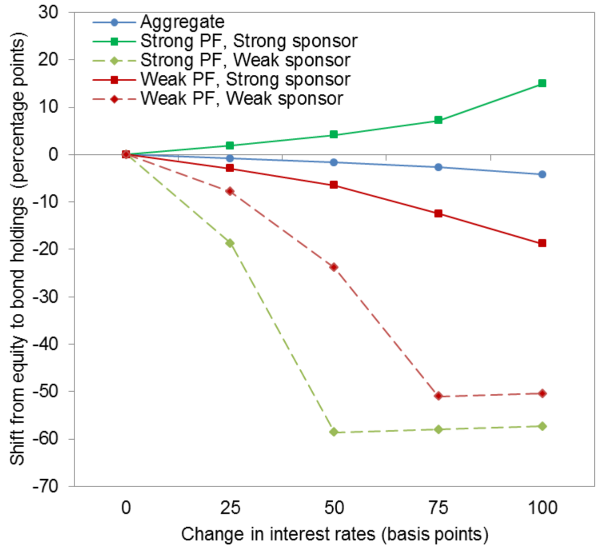
Source: Model outputs

The estimated investment response of the aggregate fund to falls in interest rates is similar to those of the two pension funds supported by stronger sponsors. That is, it is also expected to largely sit on its assets in the face of falling interest rates. Further, for all of the pension cohorts that we examine, the estimated investment response functions to falling rates are broadly linear with the shock magnitude over a range of plausible shock sizes.

Modest increases in rates

Increases in the risk-free rate, which lead to improvements in pension funds' funding ratios, tend to result in the inverse of the above result for falls in the risk-free rate. In particular, Chart 5 shows our model estimates for how pension funds would adjust their bond holdings (by reducing their equity holdings) in the face of exogenous increases in the risk-free rate that cause funding ratios to increase modestly (i.e. where funding ratios are still less than 100%).

***Chart 5**: Estimated change in pension funds' bond holdings for modest increases in risk-free rates*



Source: Model outputs

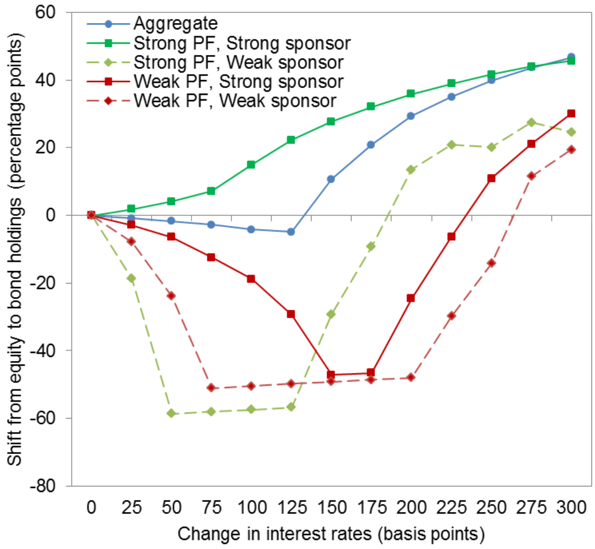
As for the scenario of falling risk-free rates (described above), the two pension cohorts supported by stronger sponsors are expected to behave broadly acyclically in bond markets – that is, they merely sit on their holdings in the face of rising interest rates (i.e. falling bond prices).

In contrast, the two pension cohorts supported by weaker sponsors are expected to invest procyclically in bond markets – that is, reduce their holdings as prices fall (due to rising risk-free rates). In particular, for sufficiently large shocks to risk-free rates, these funds are expected to sell the vast majority of their equity holdings – hence, the observed levelling-off of their equity sales for increases in risk-free rates of 75 to 100 basis points.

Larger increases in rates

More material increases in risk-free rates that cause pension funds' funding ratios to approach and increase beyond 100% can give rise to different investment incentive to those described above. In particular, as pension funds' funding ratios near 100%, they may find it optimal to ***'lock in'*** those funding positions by increasing their bond holdings (and reducing equity holdings). Increased bond holdings, which better hedge future changes in the value of pension liabilities, reduce the likelihood of funding ratios falling and, therefore, of increases in the corporate sponsors' required pension contributions.[11]

Chart 6: *Estimated change in pension funds' bond holdings for material increases in risk-free rates*



Source: Model outputs

Chart 6 shows that more material increases to risk-free rates give rise to non-linear investment responses across the different pension cohorts. This is consistent with the above intuition around pension funds' desire to lock in funding ratios above 100% by increasing their bond holdings. And the magnitude of interest rate increases required to induce this lock in behaviour varies across pension cohorts. The two pension funds with stronger initial funding ratios appear to respond to these lock in incentives for increases in risk-free rates of around 75 - 150 bps, compared to 175 – 225 bps for funds with weaker initial funding ratios.

The above findings are consistent with those from Blake et al (2013), which finds that once defined contribution pension funds are above their 'targets', they reduce their equity allocations.

The magnitudes of the interest rate changes required to induce this *lock-in* behaviour are extreme but plausible: there are only few occasions where risk-free rates have risen to such extents over a six month horizon (i.e. the time horizon of the model). For example, during the so-called 'Taper Tantrum' in summer 2013, when the US Federal Reserve indicated that it would soon start to reduce its asset purchasing programme, 15-yrs gilt yields increased by approx. 90bps over a four month period.

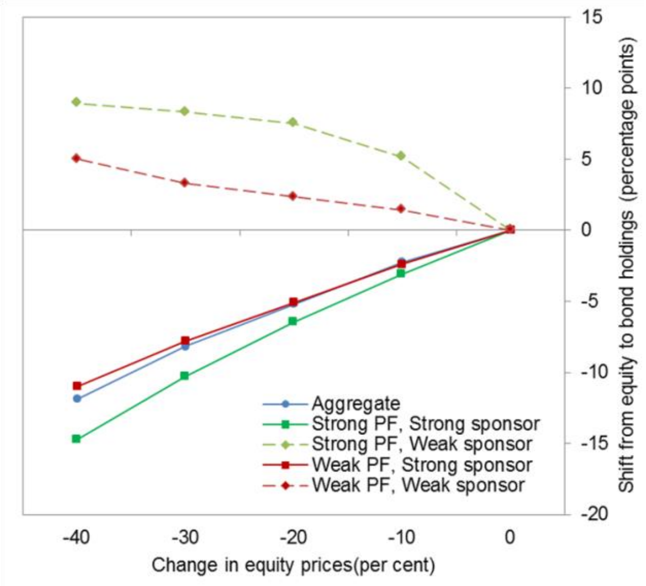
Shock to equity prices

We simulate exogenous *falls* to equity prices. These matter for pension funds: by reducing the value of pension assets and leaving the value of pension liabilities unchanged, they cause funding ratios to deteriorate. Falling equity prices therefore give rise to the same competing incentives (i.e. the 'expected pension contributions' and 'sponsor vulnerability' channels) as for when risk-free rates fall.

Chart 7 shows our model estimates for how pension funds would adjust their bond holdings (by reducing their equity holdings) in the face of exogenous percentage falls in equity prices. The net outcome of these competing incentives varies across cohorts.

[11] Achieving a funding ratio of over 100% tends to be a requirement for corporate sponsors' to offload the risks associated with their pension funds through so-called 'buy-out/buy-in' markets. This is where corporate sponsors pay a premium to insurance companies to take on the risks associated with their pension funds. We do not model this aspect of corporate sponsor behaviour.

Chart 7*: Estimated change in pension funds' bond holdings for given percentage falls in equity prices*



Source: Model outputs

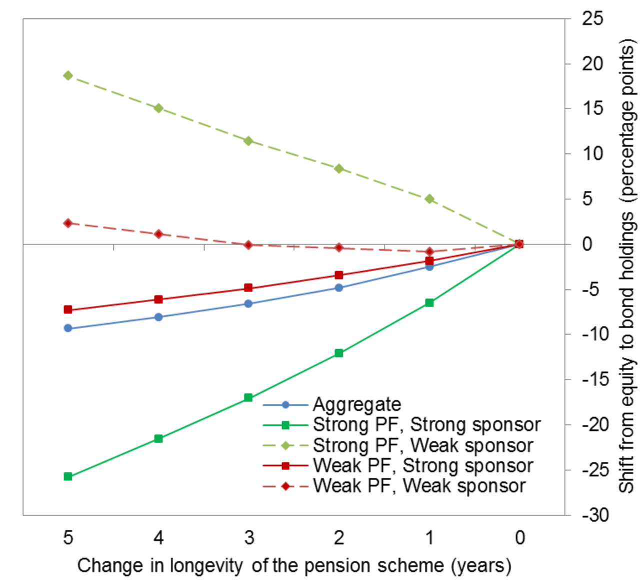
For the two pension cohorts supported by stronger sponsors, the incentive to switch into equities in the face of higher expected required pension contributions dominates. Hence, these two pension cohorts are expected to invest countercyclically in equity markets – that is, increase their holdings as prices fall.[12] This is also the case for the aggregate fund. In contrast, for the two pension cohorts supported by weaker sponsors, the incentive to switch into bonds (and away from equities) in the face of increased perceived risks for the corporate dominates. Hence, these pension cohorts invest procyclically in equity markets.

Shock to longevity expectations

We simulate exogenous increases to longevity – that is, the risk that individuals live longer than expected. We model these longevity shocks by increasing the number of years over which pension funds must make payments to pension members. Increases in longevity expectations matter for pension funds: funding ratios tend to deteriorate as the present value of pension liabilities increases whilst the value of pension assets remains unchanged.

Chart 8 shows our model estimates for how pension funds would adjust their bond holdings in the face of exogenous increases in longevity expectations (in years). The results for the various pension cohorts are strikingly similar to the results for the equity price shock, described above. That is, the two pension cohorts supported by *stronger sponsors* are expected to switch into equities (driven by the 'expected pension contributions' channel), whereas those cohorts supported by *weaker sponsors* are expected to switch into bonds (driven by the corporate vulnerability channel).

Chart 8*: Estimated change in pension funds' bond holdings for given increases in the assumed*



Source: Model outputs

[12] There are factors that may limit the degree of such countercyclical behaviour. For example, the conservative mind-set of pension trustees may limit pension funds' willingness to buy equities in the face of falling prices.

The magnitudes of the exogenous increases in longevity assumptions required to induce the above behaviour are quite extreme by historical standards. For example, over the ten years leading up until 2016, the Office of National Statistics estimates that the life expectancy of men and women in the UK at the age of 65 increased by only around 1.4 and 1.1 years, respectively.

Section 7: Conclusion and policy implications

We have developed a structural model to explain UK defined benefit pension funds' investment behaviour. We use the model to estimate how pension funds can be expected to adjust their asset portfolios in the face of different exogenous shocks.

We find that pension funds' response to shocks varies across different cohorts of pension funds. Funds supported by financially weaker corporate sponsors are expected to increase their bond holdings following adverse shocks that deteriorate their funding ratios – that is, the ratio of the value of pension assets to liabilities. This is because they look to reduce the perceived vulnerability of their sponsors. In contrast, following the same shock, funds supported by financially stronger corporates are expected to increase their equity holdings to benefit from their higher expected returns. Further, for exogenous shocks that cause funding ratios to approach and increase beyond 100%, we find evidence that all of our pension cohorts look to 'lock-in' improved funding positions by increasing their bond holdings.

These findings are relevant to financial stability policymakers concerned about the adverse effects of *procyclical* investment behaviour – that is, selling in response to price falls, and vice versa. In **Table 3** we provide a summary of the model results for each of our exogenous shocks, indicating using the symbol '*' whether the estimated investment response is procyclical. Procyclical behaviour can amplify shocks, causing asset prices to overshoot their fundamental values (e.g. see Bank of England (2014)). Our model suggests that pension funds supported by *weaker sponsors* behave procyclically in response to rises in bond prices (driven by falling risk-free rates) and in response to falls in equity prices. Whilst our model does not directly examine the amplifying impact of such behaviour on asset prices, our results suggest that models of the amplification of shocks in the financial system as a whole should incorporate the heterogeneity of different pension funds investment behaviour.

Our findings have implications for policy issues beyond the scope of this paper. For example, we find that – unsurprisingly – pension funds' asset allocations are particularly sensitive to interest rates. Hence, an increase in interest rates towards levels broadly consistent with those observed before the Global Financial Crisis could encourage funds to purchase material volumes of additional bonds (as they seek to lock-in improved funding ratios). These bond purchases, which would occur as prices are falling due to higher yields, could support bond market liquidity and provide an important source of demand for the UK Debt Management Office's future issuance of government debt.

***Table 3**: Summary of model results*

Shock type		Estimated investment response in bond markets for…				
		Stronger sponsor, stronger fund	**Stronger sponsor, weaker fund**	**Weaker sponsor, stronger fund**	**Weaker sponsor, weaker fund**	**Aggregate fund**
Risk-free rate fall		No material change	No material change	Buy bonds *	Buy bonds *	No material change
Risk-free rate increase	Modest magnitudes (where funding ratios remain below 100%)	No material change	No material change	Sell bonds *	Sell bonds *	No material change
	Material magnitudes (where funding ratios approach and exceed 100%)	Buy bonds	Buy bonds	Buy bonds	Buy bonds	Buy bonds
Equity price fall		Sell bonds	Sell bonds	Buy bonds *	Buy bonds *	Sell bonds
Longevity expectations increase		Sell bonds	Sell bonds	Buy bonds	Buy bonds	Sell bonds

* This indicates that the estimated investment response is *procyclical* – that is, the pension fund sells as asset prices fall, and vice versa. **Source**: Model outputs

References

Alderson, M.J. and Seitz, N.L. (2013). 'Pension Policy and the Value of Corporate-Level Investment'. Financial Management, Summer 2013. 413-440.

Bank of England (2014). "Procyclicality and structural trends in investment allocation by insurance companies and pension funds". A Discussion Paper by the Bank of England and the Procyclicality Working Group. July 2014. https://www.bankofengland.co.uk/-/media/boe/files/paper/2014/procyclicality-and-structural-trends-in-investment

Bernadette A. Minton, Catherine Schrand, "The impact of cash flow volatility on discretionary investment and the costs of debt and equity financing", Journal of Financial Economics, Volume 54, Issue 3, December 1999, Pages 423-460.

Blake, D. (2003). 'UK pension fund management after Myners: The hunt for correlation begins'. Journal of Asset Management, Vol. 4. 1, 32-72.

Blake D., Sarno, K. and Zinna, G. (2017). "The market for lemmings: The herding behavior of pension funds". Journal of Financial Markets. Volume 36, November 2017, Pages 17-39.

Blake, D., Wright, D. and Zhang, Y. (2013). "Target-driven investing: Optimal investment strategies in defined contribution pension plans under loss aversion". Journal of Economic Dynamics & Control 37: 195-209.

Bodie, Z. (1990). 'The ABO, the PBO and Pension Investment Policy'. Financial Analysts Journal 46:27-34.

Bunn, P., Mizen, P. and Smietanka, P. (2018). "Growing pension deficits and the expenditure decisions of UK companies", Bank of England Staff Working Paper No. 714

Campbell, J. Dhaliwal, D, and Schwartz, W. (2012). "Financing constraints and the cost of capital: evidence from the funding of corporate pension plans." *Review of Financial Studies* 25.3 (2012): 868-912.

Chen, X., Yu, T., and Zhang, T. (2013). 'What Drives Corporate Pension Plan Contributions: Moral Hazard or Tax Benefits?'. Financial Analysts Journal, Volume 69, No. 4.

Clacher, I. and Moizor, P. (2011). "Accounting for Pensions". Leeds University Business School Report.

Cocco, J. F. and P. F. Volpin (2007). "Corporate governance of pension plans: the UK Evidence." Financial Analysts Journal: 70-83.

Dinenis, E. and A. Scott (1993). "What determines institutional investment? An examination of UK pension funds in the 1980s." Oxford Economic Papers: 292-310.

Dison, W. and Rattan, A. (2017). "An improved model for understanding equity prices". Bank of England Quarterly Bulletin 2017 Q2, 86-97

Douglas, G., Noss, J., and Vause, N. (2017). The impact of Solvency II regulations on life insurers' investment behaviour. Bank of England Staff Working Paper No. 664.

Eich, F. and Saleheen, J. (2017). "Low for long: what does this mean for defined-benefit pensions in the UK?". Bank Underground blog, https://bankunderground.co.uk/2017/03/02/low-for-long-what-does-this-mean-for-defined-benefit-pensions-in-the-uk/

Harrison, J.M. and Sharpe W.F. (1983). ‘Optimal Funding and Asset Allocation Rules for Defined Benefit Pension Plans’, in Z. Bodie and J. Shoven (eds.), Financial Aspects of the U.S. Pension System, Chicago, IL: University of Chicago Press.

IMF (2017). ‘Global Financial Stability Report, April 2017’, Chapter 2: Low growth, low interest rates, and financial intermediation, Box 2.3

Jin, L., Merton, R.C., and Bodie, Z. (2006). ‘Do a firm’s equity returns reflect the risk of its pension plan?’. Journal of Financial Economics 81 (2006) 1-26.

Markowitz, H. (1952). “Portfolio Selection”. The Journal of Finance. Volume 7, Issue 1. March 1952. Pages 77-91

McCarthy, D. and D. Miles (2011). "Optimal portfolio allocation for corporate pension funds." European Financial Management.

McKillop, D., and Pogue, M. (2010). ‘Pension Plan Risk: The Impact upon Financial Markets’. Report 114 ACCA

Merton, R. (1974). “On the pricing of corporate debt. The risk structure of interest rates”, Journal of Finance 29, 449-470, 1974.

Pension Protection Fund (2017). “Purple Book 2017”
http://www.pensionprotectionfund.org.uk/Pages/ThePurpleBook.aspx

Rauh, J. D (2006). "Investment and financing constraints: Evidence from the funding of corporate pension plans." *The Journal of Finance* 61.1 (2006): 33-71.

Rauh, J. D. (2009). "Risk shifting versus risk management: Investment policy in corporate pension plans." Review of Financial Studies, 22(7): 2687-2733.

Sharpe, W.F. (1976). ‘Corporate Pension Funding Policy’. Journal of Financial Economics 3:183-93.

Sundaresan, S. and F. Zapatero (1997). "Valuation, optimal asset allocation and retirement incentives of pension plans." Review of Financial Studies, 10(3): 631-660.

Tobin, J. (1958). "Liquidity preference as behavior towards risk." The review of economic studies, 25(2): 65-86.

Treynor, J. (1977). ‘The Principles of Corporate Pension Finance’. Journal of Finance 32:627-38

Vasicek, O. (1977). “An equilibrium characterization of the term structure”. Journal of Financial Economics 5 (1977) 177-188.

Webb, D. C. (2007). "Sponsoring Company Finance, Investment and Pension Plan Funding*." Economic Journal, 117(520): 738-760.

XPS (2018). “XPS Investment LDI Report: unique insights for UK pension schemes”
https://www.xpsgroup.com/news-views/xps-investment-ldi-report-unique-insights-for-uk-pension-schemes/

Annex 1: Model parameters

Description of different agents' roles in the asset allocation decisions of UK defined benefit pension funds[13]

Key players	What they do?	Role in asset allocation
Board of pension trustees	They manage the pension fund on behalf of pension beneficiaries. Some members of the board are chosen by pension beneficiaries and some by the sponsor.	The trustees have legal control over the asset allocation decision. They are responsible for ensuring that pension beneficiaries are given what is owed to them.
Sponsor	The pension fund sits on the sponsor's balance sheet. The sponsor makes regular contributions into the pension fund to ensure that there are sufficient funds to meet obligations to pension beneficiaries.	The sponsor seeks to influence the asset allocation decision through negotiations with trustees. It aims to achieve the asset allocation that maximises the value of its shareholder equity.
Investment Consultants	They provide advice on the asset allocation decision. They are paid a fee for this advice.	They provide unbiased advice to the trustees on the asset allocation decision. Their advice can play an important role in the asset allocation process by influencing other agents' views.
Actuarial Consultants	They assist in calculating the value of pension liabilities, and therefore the pension fund's funding ratio. They are paid a fee for this service.	They have no direct impact on the asset allocation decision. But they may indirectly impact other agents' behaviour through their estimation of the pension fund's funding ratio.
Pension Protection Fund (PPF)	The PPF compensates pension members where, due to and insolvency event, the sponsor is unable to provide further contributions to plug a pension deficit. To fund itself, the PPF charges an annual levy on member pension funds.[14]	The PPF has no direct impact on the asset allocation decision. But it may indirectly impact other agents' behaviour through the incentives induced by its compensation scheme.
The Pensions Regulator (tPR)	tPR regulates private defined benefit pension funds. It sets rules on various issues, including the way in which pension liabilities are valued and the time horizon over which sponsors must close pension deficits.	tPR has no direct impact on the asset allocation decision. But it may indirectly impact other agents' behaviour through its regulations.

[13] Due to a combination of legislative changes and information advantages, the influence of some agents (i.e. investment and actuarial consultants, the PPF and tPR) on trustees and sponsors has increased in recent years.
[14] A larger levy is charged to pension funds with lower funding ratios. That is, lower funding ratios attract a form of tax. In our model, we abstract from levies paid to the PPF.

Annex 2: Model parameters

Below are the model parameters that describe the financial asset price processes:

Type of parameter	Parameter	Description	Value
Equity price process	σ_0^E	Volatility of equity price at time zero (%)	16.39
	β^E	Long-term average equity price volatility (%)	16.39
	α^E	Speed of adjustment of equity price volatility to long-term average (%)	27.61
	ξ^E	Risk premium on equity (i.e. equity risk premium) (%)	7.34
Risk-free rate process	r_0^f	Interest rate at time zero (%)	2.14
	β^{r_f}	Long-term average risk-free rate (%)	3.27
	α^{r_f}	Speed of adjustment of risk-free rate to long-term average (%)	31.98
	σ^{r_f}	Volatility of risk-free rate (%)	0.75
Bond price process	ξ_0^{CB}	Corporate bond spread at time zero (%)	5.23
	$\beta^{\xi^{CB}}$	Long-term average corporate bond spread (%)	4.45
	$\alpha^{\xi^{CB}}$	Speed of adjustment of corporate bond spread to long-term average (%)	17.29
	$\sigma^{\xi^{CB}}$	Volatility of corporate bond spread (%)	1.50
	$\rho^{E,\xi^{CB}}$	Correlation between equity price and corporate bond spread	-0.27
	w^{GB}	Proportional holdings of government bonds (i.e. asset weight) in bond portfolio (%)	50.0

Below are the model parameters that describe the pension fund and corporate balance sheets

Type of parameter	Parameter	Description	Values for the…				
			Aggregate fund	**Stronger sponsor, stronger fund**	**Stronger sponsor, weaker fund**	**Weaker sponsor, stronger fund**	**Weaker sponsor, weaker fund**
Initial values of pension fund balance sheets	A_0	Initial values of pension fund assets (£bn)	1290	486	399	139	266
	L_0	Initial value of pension liabilities (£bn)	1533	530	460	180	363
	ξ^L	Risk premium on pension liabilities (%)	1.37	1.48	1.23	1.52	1.27
Corporate earnings	π_0	Corporate earnings at time zero (£bn)	362	251	33	43	35
	ξ^π	Expected growth of corporate earnings in excess of the risk-free rate (%)	6	9	3	9	3
	σ^π	Volatility of corporate earnings (%)	126	72	179	72	179
	$\rho^{E,\pi}$	Correlation between the equity price and corporate earnings	0.75				
	$\tau^{Contributions}$	Time horizon over which corporate is required to close the pension deficit (years)	7.84	6.07	7.35	9.54	10.19
Valuing the corporate's share price	ξ^{Widget}	Risk premium demanded by equity investors to invest in corporate's widget business	This parameter is used to calibrate the model. See **Section 5** for model calibration results.				