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Assessing the effects of unconventional monetary policy and low interest rates on pension funds risk incentives

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Abstract

In this article the role of unconventional monetary policy and low interest rates are amplified as one of a series of components of possible explanations on US pension funds risk taking and asset allocation behavior. We quantify the effects of persistently low interest rates near to the zero lower bound, and the unconventional monetary policy adopted by the Federal Reserve by using counterfactual scenarios and two structural Vector AutoRegressive (VAR) models. We provide the first comprehensive evidence showing that monetary policy shocks, identified as changes in interest rates that lead to larger or smaller changes in Treasury yields, are followed by a substantial increase in equity assets. The shift from Treasury bonds to equity securities is greater during the unconventional monetary policy period. We document a positive correlation between pension fund risk taking, low interest rates and the decline in Treasury yields across well-funded and underfunded pension plans, which is consistent with a structural risk shifting incentive.

JEL classification: G23; E52; G11.

Keywords: Pension funds; Unconventional monetary policy; Asset allocation; Interest rates.

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1. Introduction

“More than half of the largest local governments in the U.S. have liabilities from pension underfunding that exceed 100% of their revenues” (Moody’s Investors Service, Global Credit Research, 26 September 2013).

Over the last decade, underfunded pension obligations have been a credit pressure and a key to a broader retirement crisis. The rise in life expectancy, which increases liabilities significantly (see also Cocco and Gomes, 2012, for the role of longevity risk on saving and retirement decisions), and the immense challenges in the asset allocation landscape, render the financing of these liabilities more difficult than ever (Cocco et al., 2005). Official estimates of US public pension fund shortfalls are in the range of \$700 billion to \$1 trillion, while the financial meltdown of 2008 exacerbated the underfunding problem.² In the aftermath of the last financial crisis, the average ratio of pension assets to liabilities (the funding ratio) plummeted from 95% as of fiscal year-end 2007 to 64% by fiscal year-end 2009, and recovered modestly to 74% for the 2013 fiscal year.³ However, this recovery in assets is not sufficient to cover US pension liabilities.

The severe funding gap has triggered increased interest among academics, practitioners, and policymakers in understanding the investment strategy and risk taking behavior of the public pension fund industry. Evidently, US public pension funds have been investing an ever-increasing proportion of their assets in risky investments and equities.⁴ In particular, Rauh (2009) finds that private pension plans have departed from traditional investments, such as government bonds, and are heavily invested in risky securities, such as equities, and in alternative assets, such as hedge funds, private equities and real estate investment trusts, to

² This figure is obtained using the calculation and actuarial method of the US Census Bureau.

³ Please see Appendix B for a detailed presentation of the most underfunded state pension plans.

⁴ In the United States, the Public Fund Boards, which govern public pension funds, decides on the allocation of assets. To the extent that pension funds are largely unconstrained in the proportion of funds that can be invested in risky assets and in their assumptions on the expected rate of return of the various asset classes, they have significant latitude to choose their assets and the liability discount rate.

achieve higher return. Notably, the author also finds that changes in the allocation of pension fund assets seem to be motivated by risk management, rather than risk shifting incentives. However, Mohan and Zhang (2014), find that risk shifting incentives dominate in US public pension funds asset allocation decisions. The empirical literature on determining optimal asset allocation for public pension funds has not settled this issue. For instance Campbell and Viceira (2001), and Cochrane (2014) among others, show that investments in stocks can be less risky and more profitable for long horizon portfolios, while other studies advocate a more conservative approach (e.g., Bader and Gold, 2007). According to Lucas and Zeldes (2009) the accounting rules for public pensions create an irregular incentive to invest in equities since projected liabilities are discounted and calculated on the basis of expectations for investment return, instead of discounting them at a rate that reflects the risk of the liabilities. Novy-Marx and Rauh (2011) corroborate on this study to document that pension funds exploit a loose regulation to camouflage their liabilities by investing in the stock market, which results in a higher discount rate being allowed for their liabilities.⁵ Contrary to Rauh (2009), these findings indicate that pension plans asset allocation decisions are dictated by risk shifting, rather than risk management incentives.

Motivated by the conflicting results reported in the literature, we examine whether the new monetary policy era, with low interest rates and the launch of unconventional monetary policy is one of a series of components affecting pension funds risk taking and asset allocation decisions.⁶ Over the last two decades, the US monetary policy framework has undergone dramatic changes. Interest rates decreased near to the zero lower bound to overcome the stock market crash of 2001 and the subprime crisis and the financial turmoil of 2008. With single

⁵ There are typically minimum funding requirements imposed by regulation in the US pension fund industry. In particular, the required minimum contributions are calculated on the basis of amortizing existing underfunding over a time period of 30 years, while the higher the assumed invested return, the lower the required contribution by pension fund members.

⁶ Building on Rauh (2009, p. 2689), a risk management incentive is defined “when well-funded pension funds invest in more risky securities, while underfunded pension funds invest in less risky assets.”

digit inflation and substantial financial downturns, the monetary authorities also launched a variety of unconventional measures, including increases in money supply to buy short-term government bonds and asset purchases, in response to specific challenges caused by the 2007–2008 global financial crisis (see, e.g., Adam and Billi, 2007; D’Amico et al., 2012; Gali, 2014; Neely, 2015). These measures, widely known as “quantitative easing”, were subsequently adopted by other major central banks such as the Bank of England and the European Central Bank and have been found to improve economic and financial conditions (see also for relevant discussion and empirical findings in Kapetanios et al., 2012; Joyce et al., 2012; Chen et al., 2012; Gambacorta et al., 2014). However, US public pension funds deficits remain stubbornly high even though market conditions have improved in the post-crisis period. For instance, Franzoni and Marin (2006), argue that the combination of a deep stock market downturn and the fall in interest rates from 2000 till 2002 led to a \$400billion loss on the funding status of US pension plans. While there is a “practitioner view” that the new monetary policy era with low interest rates affects pension funds, surprisingly there is no support for this view from empirical works. Do low interest rates create an incentive for pension funds to invest their assets in risky securities? Is there any effect on pension funds risk taking behavior from the launch of the unconventional monetary policy? The influence of monetary policy in favor of risk taking in pension funds has been ignored by the literature, which instead emphasizes on endogenous factors (e.g., level of underfunding, fiscal and regulatory constraints, and effective risk management skills) that affect strategic asset allocation decisions (Rauh, 2006; Aglietta et al., 2012; Blake et al., 2013; *inter alia*). There are, therefore, several theoretical reasons why pension risk might substantially increase, leading to risk shifting instead of risk management incentives.

To assess the impact of unconventional monetary policy and low interest rates on pension funds we initially use a regression analysis to identify how asset allocation changes

over time, during different interest rate levels and monetary policy regimes. Similar to Kapetanios et al. (2012), in order to quantify the role of monetary policy, we define changes in the interest rates that lead to larger or smaller changes in bond yields, as monetary policy shocks. We employ a Bayesian Vector AutoRegressive (BVAR) model estimated over rolling windows to allow for structural changes as well as to consider uncertainty about the probability distributions of the system's variables when analyzing the impulse response functions. This model is appropriate because it enables an analysis of complex interrelationships, which involves in our case the interconnections between Treasury yields, interest rates, and asset and risk management decisions. We use this model to conduct a counterfactual analysis to show that Treasury yields would have been higher, *ceteris paribus*, in the absence of drastic changes in the monetary policy framework. This intuition is built on the link between government bond yields and interest rates proposed by Estrella (2005), and is similar in spirit to Kapetanios et al. (2012).⁷ Moreover, we develop a Markov-switching structural VAR (MS-SVAR) model that relaxes the assumption of constant parameters over time and therefore enables us to incorporate a more sophisticated treatment of potential structural changes across different regimes (see also, Waggoner and Zha, 2003; Primiceri, 2005). Motivated by Kapetanios et al. (2012), the underlying structural shocks are identified through restrictions on the impulse responses. Notably, the use of different models that vary in their emphasis increases the robustness of our findings.

The results in our study indicate that low interest rates near the zero lower bound, and the launch of unconventional monetary policy prompted a gradual increase in equity assets and in pension fund risk taking behavior. Additionally, risk shifting incentives to avoid low-yield investments (such as Treasury bonds) in favor of more risky investments (such as equities and alternative assets) dominate pension fund asset allocation decisions. More precisely,

⁷ Additional information on this approach is provided in Sections 3.2 and 3.5.

in an important departure from prior studies, we separate our sample into different time periods to capture the effect of monetary policy shocks on pension fund risk-taking behavior. The results over the whole sample period initially suggest that asset allocation is correlated with short-term lagged investment returns, and higher returns precede higher equity allocation. Given that from the 2001 till 2007 the equity market increased considerably, this provides evidence for procyclicality since an increase in the stock market triggers an increase in equity holdings. However, the results for the sub-periods uncover the absence of correlation between asset allocation and short-term lagged investment returns since 2007–2008. Particularly, the slump of the stock market in 2007 – 2008 was not followed by a reduction in equity assets, which implies that there is a structural shift out of bond assets. Moreover, the risk management incentive is not the primary reason for the reduced allocation to Treasury bond investments in pension funds.

If risk management is not the reason that pension funds decrease their investments in safe assets and increase their allocations to equities and alternative assets, then what is? We find a positive correlation between risk taking and reductions in interest rates that lead to a decline in Treasury yields across well-funded and underfunded pension funds, which is consistent with a structural risk shifting incentive. In other words, pension funds risk taking and asset allocation behavior is affected by monetary policy shocks. In particular, we uncover that a reduction in interest rates which is followed by a decline of 5% in the 10-year Treasury yield over the period 1999–2014 is associated with an 18% decrease in the allocation of bond securities and a 17% increase in the allocation to equity assets, across well-funded and underfunded plans. As a result, monetary policy shocks associated with lower interest rates, and lower Treasury yields, trigger meaningful changes in asset allocation, in favor of risky investments.

Further results from the counterfactual analysis with the use of the BVAR model suggest that, in a higher interest rate environment without significant declines in Treasury yield, the investment return from bond securities would have been significantly larger, from 6.56% to 7.19% for a 100 basis point rise in the 10-year Treasury yield and to 7.68% for a 200-basis-point appreciation in the yield, which is similar to the return for assets allocated to bonds. Consistent with Lucas and Zeldes (2009), we find that pension plans assume an unrealistically high expected rate of return, which they fail to reach on average. Concretely, the mean investment return across the group of pension funds is close to 8%. This is also used as the typical liability discount rate. Thus, a high expected return protects future pensioners from having to increase their contributions. If risky assets perform well, then the subsequent improvement in pension funding reduces the need for increased contributions. Notably, in many cases, the assumed higher level of interest rates would have helped many funds to achieve their planned return of 8%. Simultaneously, portfolio risk would have been substantially lower. Therefore, the low interest rate environment and the use of unconventional monetary policy prompt a re-allocation of pension fund assets, leading to increased allocations to risky investments. The MS-SVAR model generates similar evidence, suggesting that the risk taking behavior of pension funds is affected by low interest rates and unconventional monetary policy. In particular, annual investment return increases significantly from 6.56% to 7.74%. However, conclusions are drawn cautiously as other factors which might have an important role on pension fund asset allocation decisions are not examined in this study, and therefore, monetary policy is one of a series of possible explanations for the risk taking behavior of pension plans.

This article makes an important contribution to our understanding on the determinants of pension fund risk taking behavior. We go one step further from the works of Rauh (2009), Lucas and Zeldes (2009), and Mohan and Zhang (2014), since it is the first study to explicitly

account for exogenous factors that contribute to pension fund risk behavior. Specifically, the role of unconventional monetary policy and low interest rates is amplified as one of a series of components of pension plans risk taking and asset allocation decisions. Moreover, we contribute to the debate on the dominant role of risk shifting and risk management incentives on pension plan asset allocation. Empirical evidence on the dominance of risk shifting in pension funds risk taking behavior is particularly thin. Rauh (2009) finds no evidence that pension funds, and particularly financially distressed funds, engage in risk shifting behavior. On the contrary, the observed correlations between asset allocation and lagged investment returns, implies that changes in the allocation of assets are prompted by an incentive for efficient risk management. Mohan and Zhang (2014) suggest that public funds undertake more risk when underfunded, consistent with the risk transfer hypothesis. We extend their works by using a comprehensive sample of public pension funds, offering new evidence on the incentives for risk shifting in pension funds.

The remainder of this paper proceeds as follows. Section 2 discusses the relevant literature. Section 3 analyses the research questions and describes the methodology. Section 4 depicts the dataset and analyses the results. Section 5 presents robustness checks and section 6 the concluding remark.

2. Literature review

2.1 Pension fund investment incentives

Determining optimal asset allocation policy for public pension funds is an important but unsettled task. At a theoretical level, Sharpe (1976) and Treynor (1977) describe a pension liability as a contract between two parties with a put option exercisable in the event of bankruptcy and a strike price equal to the value of pension liabilities. The literature on the choice of a portfolio of assets for retirement savings starts with the argument that under spe-

cific assumptions, the goal of shareholder maximization is achieved when pension funds invest in bonds (see for example Black, 1980; Tepper, 1981; Bodie, 1990; *inter alia*). These studies assume that long-term portfolios for retirement savings refer to conservative investors, and as a result, they are typically encouraged to hold more bonds, relative to stocks. However, several empirical studies observe that on average more than 50% of US pension fund assets are invested in stock securities (Rauh, 2009; Mohan and Zang, 2014; *inter alia*). The empirical literature notifies that there are two reasons for this shift in the allocation of assets.

First, the portfolio-management landscape has changed radically. While equities have traditionally been classified as risky assets, several works provide ample evidence that equities are actually less volatile when they are measured over long holding periods, and consequently they are relatively safe assets for investors who are able to hold for the long term (see also Campbell and Viceira, 2002, Chapter 4). For instance, the existence of volatility shocks, and the associated negative correlation of these shocks with excess stock returns, implies that long-term investors should hedge volatility risk by reducing their allocation to equity securities. However, Campbell and Viceira (2001) show that volatility shocks in the US stock market is not sufficiently persistent and negatively correlated with stock returns to justify a large negative intertemporal hedging portfolio demand for stocks with bond-related assets.

In a similar vein, more recently, Cochrane (2014) shows that in a dynamic intertemporal environment, investments in stocks can be less risky and more profitable for long horizon portfolios. In particular, the author proposes dynamic trading based on state variables that change over time as a different way of constructing long-horizon portfolios of stocks. In addition, several empirical works on long-term portfolio choice provide strong evidence that a long term investor with a conservative attitude (i.e. risk averse) should hedge interest rate

risk and respond to mean-reverting stock returns by increasing the average allocation to equity securities (Campbell et al. 2003).

A second reason for the shift on the asset allocation to equity securities, rather than bonds, is supported by the US regulatory environment. While the financial theory suggests that “the discount rate used to value future pension obligations should reflect the riskiness of the liabilities” (see also Brown and Wilcox, 2009), in actual practice, pension funds set their discount rates based on the characteristics of the assets held in the portfolio, rather than the characteristics of the pension liabilities. As a result, Lucas and Zeldes (2009) show that underfunded pension funds prefer to invest heavily in higher yielding, but riskier assets, such as equities, because they expect a higher average return to reduce underfunding over time. More precisely, the accounting rules for public pension funds set by the Government Accounting Standard Board (GASB) create an irregular incentive to invest in equities, since projected liabilities are discounted at the expected return on assets rather than at a rate that reflects the risk of liabilities.⁸ Hence, investing in stocks leads to a higher allowed discount rate for the liabilities, and this in turn allows pension funds to present lower degrees of underfunding, to camouflage their shortfalls, and helps to postpone any increase for pension contribution to the future generations.

2.2 Risk shifting versus risk management incentive

As described above, recent developments in the empirical asset allocation literature and the accounting rules set for pension funds provide two arguments for the practice of investing in equity securities in long horizon portfolios. Notably, this practice is largely in parallel with private sector practices. Blake et al. (2013) document that over the last two decades there is a shift from centralized to decentralized pension fund management, since funds replace managers with “better-performing” specialists. However, in most cases, pension plans

⁸The Government Accounting Standard Board (GASB) is an independent organization that establishes standards of accounting for public (state and local) pension funds.

are severely underfunded and their investments underperform. Munnell et al. (2008), report that the increased exposure to equity securities, from an average of about 40 percent in the early 1990s to about 70 percent in 2000s, and the slump of the stock market in 2008 led to a loss of about \$1trillion dollars. In spite of the new developments in the literature, there is still much disagreement across empirical studies.⁹ Bader and Gold (2007) propose a more conservative approach by investing to bonds, to reduce the volatility of funding levels and the likelihood of severe shortfalls during financial slumps. In a similar vein, Brown and Wilcox (2009) suggest that pension funds should use risk-free real interest rates to discount their pension promises, and hence should direct an increased proportion of investment to bond related securities. Ebrahim et al. (2014) argue that the asset allocation puzzle is purely a partial equilibrium phenomenon, feasible only in the absence of capital constraints. Therefore, risk-aversion attitude (such as investments in bond yields) allows for wealth smoothing.

Rauh (2009) raises an additional critical issue for pension funds. Are these changes and the shift in the risk-taking behavior of pension funds dominated by risk management or by risk shifting incentives? In particular, a risk management incentive suggests that well-funded pension funds could invest in more risky securities (such as equities), while on the contrary, underfunded pension funds would invest in less risky assets (such as bonds). The author finds that the risk taking behavior of US pension plans is consistent with a risk management incentive. Mohan and Zang (2014), build on this work to test the risk management hypothesis, and they document that, contrary to the findings of Rauh (2009), public funds undertake more risk when they are underfunded, indicating that the risk shifting incentive dominates on US pension plans risk-taking behavior.

⁹ For an in-depth analysis and observation on this issue, see also Benzoni et al. (2007).

3. Methodological framework

3.1 Research questions development

Blake et al. (2013), and Munnell et al. (2008) among others, find that pension funds have increased their investment exposures to equity securities, from an average of about 40 percent in the early 1990s to about 60 percent in 2010s. As described in Lucas and Zeldes (2009, p. 528) an explanation for the shift in the allocation of assets is that “the accounting rules for public pensions create a perverse incentive to invest in stocks.” Moreover, some studies in the empirical literature for long horizon portfolio investments advocate this change in asset allocation. However, as described in Section 2, determining optimal asset allocation for public pension plans is an unsettled task. Some studies contradict the shift to equity securities, while also some reports argue that the increased exposure to equity assets and the slump of the stock market in 2008 led to a loss of about \$1trillion dollars.

Simultaneously, over the last two decades, the monetary policy framework entered a new era, where low interest rates became the new norm, since the early 2000s. In addition, the Federal Reserve adopted unconventional monetary policy tools as a remedy to the financial turmoil of 2008. As former Federal Reserve Chair Ben Bernanke (2015) argues, the launch of unconventional monetary policy tools, such as the zero lower bound policy, were employed to influence interest rates, to improve access to credit for businesses and households. While a great deal of research has focused on the performance, structure, and asset allocation of pension funds, and while there is a conventional wisdom that the “new” monetary policy framework with low interest rates affects pension funds, surprisingly there is no support for this view from empirical works. This study examines whether the new monetary policy era is one of a series of components that affect pension funds risk-taking behavior. More concretely, we investigate the following questions: Do low interest rates create an incentive

for pension funds to invest their assets in risky securities? Is there any effect on pension funds risk-taking behavior from the launch of the unconventional monetary policy?

Moreover, we go one step further to examine whether the new monetary policy era encourages a risk management or a risk shifting behavior in pension funds. As proposed by Rauh (2009), a risk management incentive suggests that asset allocation decisions are a function of the funding status, such that underfunded plans invest in less risky securities, while well-funded plans invest in more risky assets, such as equity assets. The author shows that the risk management incentive dominates in the US private pension funds. On the contrary, Mo-han and Zang (2014), find that the risk shifting incentive dominates in the US public pension funds. These contradictory arguments prompt us to examine whether changes in the behavior of pension funds are driven by risk shifting or risk management incentives.

To assess these questions we split our sample into four periods: i) Period 1 (1998–2000) when interest rates were between 4% – 7% and the 10-year US Treasury yield was about 7% and, hence, investments in safe assets were attractive; ii) period 2 (2001–2005) when stock markets collapsed and interest rates reached historical low levels to promote a gradual economic recovery; iii) period 3 (2006–2007) is characterized by improvements in economic conditions and significant credit expansion, which caused a moderate increase in interest rates; and finally iv) period 4 (2008–2013) corresponds to the reduction of the interest rate near the zero lower bound, while also the US Federal Reserve announced a large program of asset purchases and other unconventional monetary measures. In order to quantify the role of different monetary policy regimes on pension funds risk-taking behavior, we follow Kapetanios et al. (2012) to define that changes in interest rates which lead to larger or smaller changes in bond yields, as monetary policy shocks. This intuition is built on the link between Treasury bond yields and interest rates proposed by Estrella (2005). In addition, we examine several counterfactual scenarios in which monetary policy shocks are less persistent

(i.e. interest rates decline modestly, and therefore Treasury yields are higher), to investigate the effects on portfolio risk (i.e., beta) and how the allocation of assets to risky investments could be affected.

3.2 The BVAR model

Vector autoregressive models, as introduced in the pioneering works of Sims (1972, 1980) represent a standard benchmark for the analysis of dynamic monetary policy experiments. Our study builds on two macroeconometric models to analyze the effects of monetary policy shocks on the risk-taking behavior of pension funds. We also conduct a counterfactual analysis with respect to monetary policy shocks. More precisely, we simultaneously use a Bayesian VAR model estimated over rolling windows where parameters are treated as random and a reduced-form MS-SVAR model, in which parameters are allowed to change over time. While the former enables us to reduce parameter uncertainty and improve forecast accuracy, the latter offers the possibility to capture the potential of regime changes.

Lenza et al. (2010) and Kapetanios et al. (2012) provide a basic framework for capturing the effects of monetary policy shocks on macroeconomic variables. Motivated by these studies, we build a similar BVAR-based model

$$Y_t = \theta_0 + \theta_1 Y_{t-1} + \dots + \theta_p Y_{t-p} + e_t \quad (1)$$

where Y_t represents a vector of five variables (the pension funds allocation to equities, its allocation to cash and bonds, its allocation to other assets, pension fund portfolio beta and its return on investments), θ_0 is a vector of constants, θ_1 to θ_p are parameter matrices, and e_t is the vector white-noise error term.

We use a univariate AR(1) process with high persistence as our prior for each of the variables in the BVAR model.¹⁰ Hence, the expected value of the matrix θ_1 is $E(\theta_1) =$

¹⁰ We use a Likelihood Ratio (LR) test to obtain the most suitable number of lags. In particular, we let $R(a)=0$ to represent a set of restrictions and $\int(\alpha, \Sigma_e)$ the likelihood function. Then the $LR = 2[\ln \int \alpha^{un}, \Sigma_e^{un}) - \ln \int \alpha^{re}, \Sigma_e^{re})]$, becomes $(R(\alpha^{un})' [\frac{dR}{d\alpha^{un}} (\Sigma_e^{re} \otimes (X'X)^{-1}) (\frac{dR}{d\alpha^{un}})']^{-1} (R(\alpha^{un}))$ and we maximize the likelihood function with respect to α subject

$0.99 \times I$. We assume that θ_1 is normal conditionally on Σ , with first and second moments given by

$$E[\theta_1^{(ij)}] = \begin{cases} 0.99 & \text{if } i=j \\ 0 & \text{if } i \neq j \end{cases}, \text{Var}[\theta_1^{ij}] = \varphi \sigma_i^2 / \sigma_j^2 \quad (2)$$

where θ_0 contains a diffuse normal prior, $\theta_1^{(ij)}$ represents the element in position (i,j) in the matrix θ_1 , and the covariances among the coefficients in θ_1 are zero. Also, the prior scale and the matrix of disturbances have an inverted Wishart prior as explained in Appendix C so that $\Sigma \sim iW(v_0, S_0)$, where v_0 and S_0 are the prior scale and shape parameters, and with the expectation of Σ equal to a fixed diagonal residual variance $E(\Sigma) = \text{diag}(\sigma_1^2, \dots, \sigma_N^2)$. Our BVAR model is similar to Bańbura et al. (2010) and Kapetanios et al. (2012) since it is estimated using rolling windows to account for structural changes in monetary policy. Consequently, the shrinkage parameter φ determines the tightness of the prior which indicates the extent to which the data affects the estimates.

3.3 The MS-SVAR model

Our sample contains four regimes: (i) relatively high interest rates (and hence, Treasury yields) between 1998 and 2000 (regime 1); (ii) the stock market crash of 2001 (regime 2), which led to a dramatic decline in interest rates and in the Treasury yields; (iii) the 2007 to 2008 period, in which the federal funds target rate increased modestly and Treasury yields followed with a modest increase (regime 3); and (iv) the period from mid-2008 until the end of our sample period in 2013 (regime 4), in which the Federal Reserve decreased interest rates near to the zero lower bound (and Treasury yields collapsed) and introduced unconventional monetary measures (i.e., quantitative easing) to promote financial stability and economic development in the US. This pattern of frequent changes in the US monetary policy

to $R(\alpha)=0$. We test a VAR ($\hat{q} - 1$) against VAR ($\hat{q}$) and then a VAR ($\hat{q} - 2$) against VAR ($\hat{q} - 1$) to obtain the correct number of lags. In order to compare the results obtained by LR with other testing procedures we calculate: $T(\ln|\Sigma_e^{re}| - \ln|\Sigma_e^{un}|) \xrightarrow{D} \chi^2(v)$, where $X_t = y'_{t-1}, \dots, y'_{t-q})'$, and $X' = X_0, \dots, X_{T-1}$, is a (4×4) matrix (i.e. $m \times T$) and $v = 2$, which represents the number of restrictions.

over recent years led us to consider a regime switching structural VAR model with the following form:

$$Y_t = c + Z(A)Y_{t-1} + u_t \quad (3)$$

where Y_t is a vector of endogenous variables, c is a vector of intercepts, $Z(A)$ is a matrix of autoregressive coefficients of the lagged value of Y_t and u_t is a vector of residuals. The reduced-form error terms are related to the uncorrelated structural errors ε_t as follows:

$$\varepsilon_t = B^{-1}u_t \quad (4)$$

The vector of endogenous variables (Y_t) includes the following four variables in the VAR system:

$$Y_t = [PFEA_t, PFBA_t, PFTA_t, PFAB_t, PFR_t] \quad (5)$$

where $PFEA_t$ represents the pension fund's allocation to equities, $PFEB_t$ its allocation to cash and bonds, $PFTA_t$ its allocation to other assets, $PFAB_t$ its asset beta, and PFR_t its return on investments.

We modify the regime switching structural VAR model in Equation (3) to allow for changes in the policymaker's reaction (i.e., regime changes) and to study how pension funds are affected. Thus, we propose an MS-SVAR model with non-recurrent states where transitions are allowed in a sequential manner. Hence, to move from regime 1 to regime 4, the process has to consider regime 2 and regime 3. Similarly, transitions to past regimes are not allowed. In particular:

$$Y_t = c_s + \sum_{j=1}^k B_{j,s} Y_{t-j} + A_{0,s} \varepsilon_t \quad (6)$$

Following Jin et al. (2006) and Mohan and Zhang (2014), we measure the pension asset beta as the weighted average of individual asset betas, i.e., *Pension Asset Beta* = $\sum_{i=1}^n W_i \times \beta_i$, where W_i is the weight of each asset class with $\sum_{i=1}^n W_i = 1$, and β_i is the estimated beta of each asset class. We extend the SVAR model in Equation (3) to the case of an

MS-SVAR with non-recurrent states to account for the regime-dependent reaction of pension funds to changes in monetary policies.¹¹

As in Chib's (1998) study, the dates of the regime breaks in the model are unknown and they are modeled through the latent state variable S , which is assumed to follow an M -state Markov chain process (where M refers to the dates of the regimes) with restricted transition probabilities, such that:

$$\begin{cases} p_{ij} = p(S_t = j | S_{t-1} = i) \text{ with} \\ \quad p_{ij} > 0 \text{ if } i = j \\ \quad p_{ij} > 0 \text{ if } j = i + 1 \\ \quad p_{MM} = 1 \\ \quad p_{ij} = 0 \text{ otherwise} \end{cases} \quad (7)$$

Given the number of policy regime changes as described above, M is equal to 4 and the transition matrix is defined as:

$$\tilde{P} = \begin{pmatrix} p_{11} & 0 & 0 & 0 \\ 1 - p_{11} & p_{22} & 0 & 0 \\ 0 & 1 - p_{22} & p_{33} & 0 \\ 0 & 0 & 1 - p_{33} & 1 \end{pmatrix}$$

Alternative modeling techniques provide different relative weights to the sample and prior information. Specifically, unrestricted VARs use information very sparsely in choosing the variables, in selecting the correct lag length of the model, and in imposing identification restrictions. As a result, unrestricted VAR models may lead to poor forecasting due to overfitting the dataset (see, also, Koop, 2013). Structural and Bayesian methods provide a reliable solution for these problems as identified by De Mol et al. (2008) and George et al. (2008). By using Bayesian inference, we allow informative priors so that prior knowledge and results can be used to inform the current model. We also avoid problems with model identification by manipulating prior distributions. Therefore, this is the most suitable technique to employ for

¹¹ Note that transitions between regimes are allowed in a sequential manner, and thus to move from regime 1 to regime 4, the process must visit regime 2 and regime 3. Transitions to past regimes are also not allowed and, in a similar way to the BVAR model and Equation (5), the vector Y_t contains annual data on pension funds, and $B_{j,S}$ and $A_{0,S}$ are regime-dependent autoregressive coefficients and structural shock loading matrices respectively.

statistical regions of flat density. Moreover, an important assumption in Bayesian inference is that the data are fixed and the parameters are random. Hence, with restricted structural regimes, we do not depart from reality. An additional advantage of the use of structural regimes and Bayesian inference is that these models include uncertainty in the probability model, yielding more realistic suggestions. Also, our structural models employ prior distributions and hence, more information is used along with 95% probability intervals for the posterior distributions.

3.5 Counterfactual scenario

To produce counterfactual forecasts, we base our analysis on the empirical work of Kapetanios et al. (2012) and assume that under a different monetary policy framework, interest rates would have been higher and therefore, the 10-year US Treasury yield would have been 100, 120, or 200 basis points higher, for the whole sample period, *ceteris paribus*. In practice, we implement this impact on yields by changing the 10-year US Treasury yield spread to identify the effect of the simulations on the risk and asset allocation behavior of pension plans. Therefore, the effects of monetary policy are captured solely through lower government bond yields. We simulate two scenarios: (i) Monetary policy interventions lower interest rates and this in turn causes a downward shift in Treasury yields (i.e. monetary policy shocks); and (ii) in contrast to scenario (i) monetary policy does not change over time, monetary policy shocks are not identified, interest rates are higher and hence Treasury yields are higher. Notably, scenario (i) mimics the real monetary policy adopted by the Federal Reserve while capturing the effect of unconventional policies and low interest rates on pension fund asset allocation decisions. Accordingly, scenario (ii) assumes that interest rates and Treasury yields would have been higher and thus we adjust government bond spreads and the overnight repo rate. To identify the impact of monetary policy shocks, we compare the effect of the two scenarios on pension fund performance.

In a similar vein, Wright (2012) uses a structural VAR model to provide ample evidence that long-term interest rates and Treasury yields lowered significantly since the federal funds rate has been stuck at the zero lower bound. Using a similar model, Christensen and Rudebusch (2012) find that government bond yields declined, following announcements by the Federal Reserve and the Bank of England to buy long-term debt. Also, Weale and Wieladek (2016) use a Bayesian VAR model and document that the announcement of 1% of GDP of large-scale purchases of government bonds led to a rise of 0.58% and 0.25% in real GDP for the US and the UK, respectively. The counterfactual approach employed in this paper is similar in spirit to Kapetanios et al. (2012) and goes one step further from the existing literature because it does not simply quantify the effects of the policy on pension funds, but it also examines a “what if” scenario, hypothesizing that interest rates and Treasury yields would have been higher in a different monetary policy framework.

4. Empirical results

4.1 Data analysis and descriptive statistics

We collect detailed information about the characteristics, pension plans, and asset allocations for 151 US pension funds from January 1998 to December 2013 from the Public Plans Database (PPD) obtained from the Center for Retirement Research at Boston College. The full sample includes 2,416 observations and consists of the historical yearly asset allocation in various asset classes for each pension fund and the yearly return by asset class from 1998 to 2013, the latest year for which all data are available. Moreover, we collect, from Bloomberg database, yearly data for the 10-year US Treasury yield and the federal funds target rate (upper bound).¹² Our sample includes at least one pension fund from each state, while also it contains the largest plans based on their assets. More precisely, Table 1 shows that

¹² Please, see, Appendix A for detailed information on the pension funds used in the analysis.

there are 224 state pension plans, with 151 included in our sample. In addition, there are 3,761 local pension plans.¹³ The total number of assets for all the state and local plans is about \$3,2 billion, while our sample contains information for about \$3,0 billion of assets, which is approximately 92% of the total assets invested in the US public pension fund industry. Figure 1 shows the dynamics of the federal funds target rate and the 10-year US Treasury yield. Throughout the 1998–2013 period the Treasury yield continuously declined from 6.82% in 2000 to 1.49%. Similarly, the federal funds rate decreased from 6.5% in 2000 to 0.25% in 2013.

“Please insert Table 1 about here”

“Please insert Figure 1 about here”

Table 2 depicts the summary statistics with information on asset allocation for all pension funds during the entire sample period. More precisely, Panel A presents the assumption for annual investment return on a yearly basis as reported by the pension funds. It contains the 1-, 3-, 5-, and 10-year realized investment returns, and the funding gap ratio, which represents assets divided by actual liabilities. Any value which is lower than 1.0 implies that assets fall short of liabilities and thus the pension fund is underfunded, while a value higher than 1.0 indicates that assets exceed liabilities, and thus the pension fund is overfunded. Panel B provides the asset allocation for the pension funds and the estimated betas (i.e., the systematic risk) for the overall period for each investment.

Panel A shows that pension funds assume a high expected rate of return, but, on average, fail to reach that expectation. Hence, our descriptive summary statistics show that funds were, on average, underfunded during the sample period. Specifically, the mean investment return assumption (henceforth, the performance benchmark) is 7.86%, while the standard deviation for the assumed rate of return is 0.42%, indicating a very small variation in the return

¹³ Analytical data for the surplus or deficit and for the allocation of assets is available only for the 151 pension plans included in our sample, due to restrictions in the availability of the data set.

assumption within and across pension funds. This means that, if interest rates are below 5%, all investments allocated to government bonds and cash will underperform on an annual basis. The realized return for pension funds is much lower than the assumed rate of return. We provide the results for the average 1-, 3-, 5-, and 10-year returns and observe that pension funds underperform their expectations in each case. Indeed, the average returns are 5.58%, 5.22%, 5.36%, and 6.87%, respectively. While pension funds in some years achieved returns that were higher than their assumed returns, they usually failed to meet their target over longer investment periods.

It is worth noting that, over the 16-year period, the funds suffered several disastrous returns compared to the 8% benchmark. For instance, the low level of interest rates drove their returns much lower than the performance benchmark, while stock market crashes, which occurred in 2001 and in the financial meltdown of 2007–2008, further depressed their investments in equities. Therefore, our statistics suggest that public pension funds are assuming unrealistic investment returns, which leads to underfunding with annual contributions being based on the assumption of an 8% annual return on investment. Again, the majority of pension funds are underfunded. The mean actuarial funding ratio for 1998–2013 is 82.4% with half of the observations lying in the range of 70.0%–90.0%. The minimum (19.6%) and the maximum (197.3%) ratios suggest a high variability of pension funding status. Furthermore, the average actuarial funding ratio declines from 98.9% in 1998 to 70.61% in 2013, suggesting that underfunding worsens over the years, which is consistent with the failure to reach the benchmark return.

“Please insert Table 2 about here”

Table 3 compares asset allocation and portfolio beta by period. We observe that investments in equities and alternative assets increase meaningfully over the years. In particular, the average allocation to equities is 42.5% in period 1, and rises to 45.9% in period 2,

50.0% in period 3, and 59.6% in period 4. This increased allocation to risky assets implies an increase in risk-taking behavior by public pension funds. Accordingly, allocation to government bonds declines from 39.1% in period 1 to 22.9% in period 4. Pension funds allocating a high percentage to equities are apparently most affected by severe market downturns. More importantly, we observe that the funding gap ratio increases over the years at the same level as the proportion of equity investments increases, leading to an increased number of underfunded pension funds from period 1 to period 4. This is more evident in late 2008 and early 2009, when pension funds with large allocations in stocks were more adversely affected. Equity allocation peaked in period 4 (2008–2013) when the Federal Reserve launched unconventional monetary measures and lowered its policy rates close to the zero lower bound, confirming that these policies affect pension funds and cause an incentive for riskier investments. Figure 2 also presents in detail changes in the allocation of assets from 1998 to 2013.

“Please insert Figure 2 about here”

Similarly, portfolio beta follows an upward trend, but increases less than the equity allocation due to the increased investments in alternative assets. The allocation to short-term cash also declines over these time periods, since lower interest rates offer an unattractive alternative to pension funds, which expect a high annual return. Although the average alternative allocation over the entire period is 1.84%, it increases significantly over the period and ranges from 1.83% (period 1) to 6.3% (period 4). In summary, compared to the mean values for the entire period, bond and cash allocations are lower, while allocations in equities, alternative assets, and real estate assets are higher. Pension funds’ portfolio beta, as of 2013, is higher than the sample period average, due to the increase in equity assets and the drop in bond assets.

Moreover, Panel A of Table 3 shows that during period 1 (1998–2000) pension funds, on average, invested more in government bonds compared to all other periods. As a result,

government bonds represented a higher annual required contribution in pension fund investments. However, the lowering of policy rates close to zero and the associated decrease in the level of interest rates triggered a shift in asset allocations, from government bonds to equities and alternative investments. This is evident from the figures for period 2 in Panel B (2001–2005), period 3 in Panel C (2006–2007) and period 4 in Panel D (2008–2013). Note that average funding ratios declined over the years, and this is related with low interest rates and the unconventional monetary policy. However, conclusions are drawn cautiously as other factors which might have an important role on pension fund asset allocation decisions are not examined in this study, and therefore, monetary policy is one of a series of possible explanations for the risk taking behavior of pension plans.

“Please insert Table 3 about here”

Panel A of Table 4 presents the top 15 pension funds by liabilities. The funding coverage ratio ranges from 40% to 99%. The 5-year investment return is lower than the return assumption of 8% for all pension funds and ranges from 1.7% to 6.8%, confirming the funds’ underperformance. However, while the 10-year return presents an improved picture, only two funds achieved a rate of return exceeding the return assumption of 8%. Notably, the majority of pension funds allocate more than 50% of their investments to equities and less than 25% to bonds. Panel B depicts the funds with the higher coverage ratio. It shows that the 5- and 10-year returns are substantially higher when compared with the fund performance in Panel A. It is also evident that these funds allocate a much lower proportion of their assets to equities (32% on average) and a higher proportion to bonds (27%), suggesting that investing in equities does not imply better long-term performance.

“Please insert Table 4 about here”

4.2 Risk determinants of asset allocation

To shed light on the effects of low interest rates and the unconventional monetary policy on pension funds, we examine the relationship between monetary policy shocks, defined as changes in interest rates which lead to larger or smaller changes in Treasury bond yields, with: i) the return on pension assets during the fiscal year; and ii) the portfolio's risk (beta). Table 5 shows the regression results using pension fund asset allocation as the dependent variable, during the four different time periods. Specifically, a 10% increase in the investment return reduces the percentage of assets allocated to Treasury bonds and to short-term cash by 2.06% during period 1, and systematic risk increases by 0.42% as a result of the reduction of assets allocated to safe investments. By contrast, a 10% increase in the investment return increases the percentage of assets allocated to equities by 4.81%. This in turn increases the systematic risk of the portfolio by 0.68%.

We also find that a similar correlation exists during period 2, where a 10% increase in the investment return prompts a decrease in assets allocated to safe securities by 3.03%, while the percentage of assets invested in equity increases significantly by 6.94%. This relation implies that asset allocation is correlated with short-term lagged investment returns, with higher returns preceding higher equity and lower bond allocation. Interestingly, for pension funds with weak funding ratios (Panel B), the correlation between asset allocation and short-term lagged returns is meaningfully smaller, implying a risk shifting behavior. Notably, in periods 3 and 4, there is an increase in the proportion of alternative assets. The effect of lagged returns is statistically significant at the 5% level. As a result, the allocation of assets is not correlated with short-term lagged investment returns, since higher returns precede lower equity and bond allocation.

Notably, for all four periods, the allocation of assets is correlated with monetary policy shocks - changes in interest rates which lead to larger or smaller changes in bond yields -

since a 1% decline in bond yields leads to higher equity and lower bond allocation, as it is evident from Panels A and B of Table 5. During period 4, when the Federal Reserve announced a large program of asset purchases and at the same time lowered policy rates close to the zero lower bound, the effects are greater in magnitude. Specifically, the percentage of assets invested in bonds for a 1% decline in Treasury yields is associated with a 10.52% decrease in the percentage of assets allocated to bond securities. The effect of changes in Treasury yields is statistically significant at the 5% level.

“Please insert Table 5 about here”

Overall, our results are consistent with the patterns shown in Figures 1–2, where a reduction in interest rates that was followed by a 5% decline in the 10-year Treasury yield over the period is associated with an 18% decrease in the allocation to bond securities and a 17% increase in the allocation to equity assets. This is observed for well-funded and underfunded pension plans, indicating a structural risk shifting behavior. Consequently, a lower interest rate environment and the use of unconventional monetary policy measures prompt pension funds to change their strategic asset allocation from safe to riskier investments.

4.3 Results from the BVAR model

We estimate the BVAR model using one lag order and a rolling approach for the entire sample period. Similar to Kapetanios et al. (2012), we assume that the use of unconventional monetary policy tools, from 2008 until 2011, and the sharp drop in interest rates near to the zero lower bound may have depressed government bond yields by about 100 basis points. To assess the impact of monetary policy shocks on the asset allocation and the risk taking behavior of pension funds, we compare actual returns with those of the counterfactual scenario (i.e., government bond yields would have been 100 basis points higher than actual yields in the absence of monetary policy shocks) and take the difference between the two as our estimate. Moreover, we increase the asset allocation to government bonds and decrease the allo-

cation to equities to identify the return to pension fund investments. This procedure is also used in Lenza et al. (2010) and Kapetanios et al. (2012) when they examine the effects of unconventional monetary policy on the macroeconomy, and in Ait-Sahalia et al. (2012) when they address the effect of monetary policy shocks on financial markets. We also use two additional tests by simulating the effects of a 120-basis-point and a 200-basis-point increase in government bond yields and short-term overnight rates for cash holdings, while allowing the size of adjustment on the yields to vary over the entire sample period.

Table 6 reports the estimated effects of monetary policy shocks on pension fund investment return and asset allocation. The mean return results reveal that monetary policy shocks substantially decreased the return on bond investments, making bond assets unattractive. The largest impact occurred in period 4 (2008–2013), when the Federal Reserve launched a large program of asset purchases and at the same time reduced the official US bank rate to 0.25%. While stock markets underperform, plans do not reduce their equity holdings, indicating that there is a structural risk shifting incentive to riskier securities, such as equities and alternative investments, as a result of the policy rate cut-off to the zero lower bound. This evidence suggests that the funding status of a given pension plan changes in accordance with developments in monetary policy. Under this scenario, pension funds tend to invest more in equities and less in safe assets, such as government bonds.

How persistent are monetary policy shocks? We answer this question by examining the sensitivity of pension fund returns under the assumption that government bond yields would have been higher if there were no major changes in the Federal Reserve's policy over the sample period. The results, reported in Table 6, indicate that the portfolio return for the pension funds increases significantly from 6.56% to 7.19% for a 100-basis-point rise in yield, and to 7.68% for a 200-basis-point increase in yield. It is notable that, in many cases (i.e., in period 1 and in period 2) the assumed higher level of interest rates helps pension funds to

achieve their planned return of 8%. Figure 3 evidences the difference in return under the three counterfactual scenarios where the percentage of pension fund assets allocated to equities could be lower since investments in safer assets would be more attractive.

“Please insert Table 6 about here”

“Please insert Figure 3 about here”

In the scenario with higher interest rates, we add the assumption that investments in government bonds would be more attractive for pension funds and that they would allocate their assets accordingly. For a more meaningful comparison, the allocation to government bonds is kept constant at the proportion allocated during period 1. Table 7 presents the effects of the monetary policy on pension fund returns under these assumptions. The results indicate that the portfolio return would have been higher by 122 basis points, increasing from 6.64% to 7.86%, while the portfolio beta (systematic risk) would be substantially lower.

“Please insert Table 7 about here”

4.4 Results from the MS-SVAR model

We test for the number of regimes by prior knowledge and carry out robustness checks by using the marginal likelihood criterion as introduced by Chib (1998). Figure 4 illustrates the estimated regime pattern for pension asset allocation, while Table 8 identifies monetary policy shocks through the changes in the interest rates and the associated change in Treasury yields. In particular, Table 8 presents the effects during the four monetary policy regimes: i) during period 1 (1998–2000), when interest rates increase and reach their peak levels for the entire sample period; ii) during period 2 (2001–2005), when interest rates decrease; iii) during period 3 (2006–2007), when interest rates increase moderately; and iv) during period 4 (2008–2013), when interest rates are set at the zero lower bound and unconventional monetary tools emerge. Similar to Kapetanios et al. (2012), the shocks are identified using a sign. A positive monetary policy shock that increases interest rates is expected to

trigger an increase in the yield curve. On the other hand, a negative shock is expected to cause a compression in the yield curve.

“Please insert Table 8 about here”

“Please insert Figure 4 about here”

Figure 5 shows the impulse response functions to Treasury bonds and equity allocation following a monetary policy shock. From the figure it is clear that the monetary policy regime affects substantially the allocation of assets to equities and bonds. Specifically, the response from pension funds was to increase the proportion of equities and to decrease accordingly the proportion of assets allocated to government bonds. This finding suggests that pension funds risk taking meaningfully increases with a decline in the level of interest rates and with the launch of unconventional tools.

“Please insert Figure 5 about here”

Additionally, to capture the effects of monetary policy shocks, we follow the scenarios studied using the BVAR model, where we assume that government bond yields would have been 100, 120, or 200 basis points higher, if there had been no dramatic changes in monetary policy. Table 9 describes the effects on pension fund asset allocation and investment return from these simulations. For a 100-basis-point increase in Treasury yields, the maximum impact occurs in period 2 (2001–2005) and period 4 (2008–2013), since during these two periods the unconstrained policy rate declines. Specifically, as illustrated in Figure 6, the investment return increases significantly from 6.56% to 7.74% for a 200-basis-point rise in yield. Similar to the results of the BVAR model, in many cases, the assumed higher level of interest rates helps pension funds to achieve their planned return of 8% (in periods 1 and 2). Moreover, the MS-SVAR model indicates that, if monetary policy shocks had been less persistent, the portfolio risk (i.e., beta) would be smaller and the allocation to bond securities meaningfully higher.

“Please Insert Table 9 about here”

“Please Insert Figure 6 about here”

Similarly, we also assume that pension funds would allocate their assets according to a scenario in which investments in bond securities would be more attractive and that the allocation to government bonds would stay constant at the proportion allocated during period 1. The results obtained under this scenario, reported in Table 10, reveal that the investment return would have been higher by 122 basis points, changing from 6.70% to 7.92%, while the portfolio beta would be substantially lower.

“Please insert Table 10 about here”

5. Robustness check

The main finding of our study is that low interest rates and the launch of unconventional monetary policy (i.e., quantitative easing) trigger a risk shifting behavior for pension funds to invest in riskier securities, such as equity assets. The allocation of assets to government bonds decreased meaningfully as pension funds invested on assets with higher yield, to finance their liabilities. We test the sensitivity of our results by using different scenarios for the effect of changes in government bond yields on pension asset allocation, portfolio risk, and investment return. In this section, we adopt the Chib (1998) approach and use a particle Markov Chain Monte Carlo (MCMC) simulation to test for the number of possible regimes, since less than four, or more than four, regime switches in principle can occur. We also allow the regime to grow exponentially with time t , creating robust dependence between the state variables.

More precisely, the posterior MCMC approach, with a limit of 5,000 observations is used to compute the marginal log-likelihood values with the conditional variance depending only on past shocks.¹⁴ A high value of the log-likelihood (i.e., a value closer to zero) indicates

¹⁴ The marginal likelihood is computed in the Markov-switching models in a similar way to Hamilton and Susmel (1994).

better fitting. Table 11 presents the results estimated by bridge sampling. The differences between bridge sampling and Chib’s method are very small. Similarly, the alteration between the marginal log-likelihood values increases substantially from regimes 1 to 4, but decreases in regime 5 for all the pairs considered, as is evident in Table 11. The increased value in regime 5 implies that the four-regime model fits the data best.

“Please insert Table 11 about here”

6. Conclusion

US public pension funds suffer from severe funding shortfalls, triggered, at least partially, by the stock market crashes experienced in 2007–2008. Evidently, pension plans have been investing an ever-increasing proportion of their assets in risky investments. In an important departure from the existing literature, this study provides new evidence on the role of unconventional monetary policy and low interest rate on the US public pension funds. Our empirical analysis is based on counterfactual scenarios, a Bayesian VAR model and a Markov-switching structural VAR model. The latter allows us to analyze the complex relationships between Treasury yields, interest rates, and asset and risk management decisions, while relaxing the assumption of constant parameters over time and allowing for a more sophisticated treatment of structural changes in pension fund asset allocation strategy. We find that monetary policy shocks, defined as changes in interest rates which lead to larger or smaller changes in Treasury yields, are followed by an increase in equity assets and a decline in assets invested in bonds.

Particularly, a decrease in interest rates which is followed by a decline of 5% in the 10-year Treasury yield over the study period decreases the allocation to bond securities by 18% but increases the allocation to equity assets by 17%. The greater impact occurs during the unconventional monetary policy period with the launch of quantitative easing and the zero lower bound policy. These results imply that a lower interest rate environment and the use

of unconventional monetary policy measures prompt pension funds to change their strategic asset allocation from safe to riskier investments. However, conclusions are drawn cautiously as other factors which might have an important role on pension fund asset allocation decisions are not examined in this study, and therefore, monetary policy is one of a series of possible explanations for the risk taking behavior of pension plans.

Interestingly, we find consistent results on the reaction of pension fund investment return to monetary policy shocks, whatever the model used. Particularly, the portfolio return in pension funds increases significantly from 6.56% to 7.19% for a 100-basis-point rise and to 7.68% for a 200-basis-point increase in the yield using the BVAR approach; and from 6.56% to 7.74% for a 200-basis-point increase in the yield using the MS-SVAR approach. Notably, in many cases the assumed higher level of interest rates helps pension funds achieve their benchmark return of 8% (i.e., in period 1 and in period 2). Finally, we document that the risk management incentive is not the primary reason for the reduced allocation to Treasury bond investments in pension funds. Well-funded and underfunded pension funds invest the biggest proportion of their assets in equity securities, indicating that the risk shifting behavior dominates on the US public pension funds risk taking behavior.

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Appendix A: Data Analysis

In the US, public sector pensions are offered by three sources: The federal, state and local levels of government. Pension plans are divided into two categories namely defined benefit and defined contribution pensions. The former has been more widely used over the last years by public agencies in the US. Each state administers at least one pension system and each system has at least one pension plan. A state government usually establishes multiple pension plans within one pension system for employees with different job qualifications and tenure of service. In particular, our dataset contains: i) Public Employees' Retirement System (PERS) plans –also called Employees' Retirement System (ERS) plans– offered to all state police officers, as well as all other qualifying state government employees; ii) the Teachers' Retirement System (TRS) plan, which is offered for employees of state-sponsored educational institutions; iii) the State Retirement System (SRS), which is offered to public servants, including teachers, municipal workers, and other government employees; iv) plans for public safety personnel (PSP); and v) plans for police officers and firefighters. The number of pension systems in each state ranges from one to six — California and Texas each have six pension systems.

The major data source for the study is the Public Plans Database (PPD) obtained from the Center for Retirement Research at Boston College¹⁵. The PPD data are collected from plans, annual reports, and actuarial valuations. The sample period includes fiscal years from 1998 to 2013, and covers 151 pension systems from 50 states.

Table A1. State pension funds used in the sample

Plan Name	Plan Name	Plan Name
Alabama ERS	Alabama Teachers	Alaska PERS
Alaska Teachers	Arizona Public Safety Personnel	Arizona SRS
Arkansas PERS	Arkansas Teachers	California PERF
California Teachers	City of Austin ERS	Chicago Firefighters
Colorado School	Colorado State	Colorado Municipal

¹⁵ More information is available from the Centre for Retirement Research at Boston College at: <http://crr.bc.edu/data/public-plans-database/>

Connecticut Teachers	Connecticut SERS	Contra Tennessee County
DC Teachers	DC Police & Fire	Delaware State Employees
Denver Employees	Denver Schools	Florida RS
Georgia County Schools	Georgia ERS	Georgia Teachers
Georgia Municipal	Hawaii ERS	Idaho PERS
Illinois Municipal	Illinois SERS	Illinois Teachers
Indiana PERF	Indiana Teachers	Iowa PERS
Kansas PERS	Kentucky County	Kentucky ERS
Kentucky Teachers	LA County ERS	Louisiana SERS
Louisiana Teachers	Maine Local	Maryland PERS
Massachusetts State and Teachers	Massachusetts SERS	Massachusetts Teachers
Massachusetts ERF	Michigan Public Schools	Michigan SERS
Michigan Municipal	Minnesota PERF	Minnesota State Employees
Minnesota Teachers	Mississippi PERS	Missouri DOT and Highway Patrol
Missouri Local	Missouri PEERS	Missouri State Employees
Missouri Teachers	Montana PERS	Montana Teachers
Nebraska Schools	Nevada Police Officer and Firefighter	Nevada Regular Employees
New Hampshire Retirement System	New Jersey PERS	New Jersey Police & Fire
New Jersey Teachers	New Jersey PERF	New Mexico Teachers
New Mexico PERF	New York City ERS	New York Sate Teachers
North Carolina Local Government	North Dakota PERS	North Dakota Teachers
North Carolina State & Local ERS	North Carolina State & Local Police & Fire	Ohio PERS
Ohio Police & Fire	Ohio School Employees	Ohio Teachers
Oklahoma PERS	Oklahoma Teachers	Oregon PERS
Pennsylvania School Employees	Pennsylvania State ERS	Phoenix ERS
Rhode Island ERS	REPS Louisiana	San Diego County
San Francisco City & County	South Carolina Police	South Carolina RS
South Dakota PERS	St. Louis Indiana School Employees	St. Paul Indiana Teachers
Texas County & District	Texas ERS	Texas LECOS
Texas Municipal	TN Political Subdivisions	TN State and Teachers
University of North Carolina	Utah Noncontributory	Vermont State Employees
Vermont Teachers	Virginia Retirement System	Washington LEOFF Plan 2
Washington PERS 2/3	Washington School Employees Plan 2/3	Washington Teachers Plan 2/3
West Virginia PERS	West Utah Teachers	Wisconsin Retirement System
Wyoming Public Employees	Massachusetts State Corrections Of- ficers Retirement Plan {CORP}	Connecticut Municipal Employees Retirement System {MERS}
Iowa Municipal Fire and Police Re- tirement System {MFPRSI}	Louisiana Municipal Police Em- ployees Retirement System {MPERS}	Louisiana School Employees Re- tirement System {LSERS}
Louisiana State Parochial Employ- ees Retirement System {PERS}	Minnesota Public Employees Re- tirement Association {MPERA}[Police and Fire Retire- ment Fund]	Oklahoma Police Pension and Re- tirement System {Police System}
Utah Public Safety	Montana County Employee's Re- tirement Association {ACERA}	Wyoming County Employees Re- tirement Association {KCERA}
North Carolina City Employees Re- tirement System {LACERS}	North Carolina Fire and Police Pen- sion System {Pensions}	Montana Water and Power Employ- ees Retirement Plan {DWP}
Massachusetts County Employees	Massachusetts County Employees	Georgia City Employees Retirement

Retirement System {ERS}	Retirement System {The System}	System {SDCERS}
Georgia Municipal Employees Annuity Benefit Fund {"The Plan"}	Louisiana Police Annuity Benefit Fund {"The Fund"}	Wyoming County Employees Annuity Benefit Fund {CEABF}
Boston Retirement Board	Massachusetts Fire Dept Article 1B Pension Fund	Georgia Police Pension Fund Article 2
Georgia Municipal Pension Plan	Louisiana Police and Fire Pension System	Pennsylvania Municipal Retirement System
Massachusetts City Employees Retirement System {The System}	Chicago Teachers	South Carolina Municipal Retirement System
Missouri Fire Employees Retirement System		

Appendix B. Most underfunded pension funds in the post-credit crisis period

Rank	State	Funding ratio 2013 (%)	Funding ratio 2012 (%)	Funding ra- tio 2011 (%)	Funding ratio 2010 (%)	Funding ratio 2009 (%)	Funding ratio 2008 (%)	Median funding ratio (2008-2013, %)
1	Illinois	39.3	40.4	43.4	45.4	50.6	54.3	44.4
2	Kentucky	44.2	46.8	50.5	54.3	58.2	63.8	52.4
3	Connecticut	49.1	49.1	55.1	53.4	61.6	61.6	54.3
4	Alaska	54.7	59.2	59.5	60.9	75.7	74.1	60.2
5	Kansas	56.4	59.2	62.2	63.7	58.8	70.8	60.7
6	New Hampshire	56.7	56.2	57.5	58.7	58.5	68.0	58.0
7	Mississippi	57.6	57.9	62.1	64.0	67.3	72.8	63.1
8	Louisiana	58.1	55.9	56.2	55.9	60.0	69.6	57.2
9	Hawaii	60.0	59.2	59.4	61.4	64.6	68.8	60.7
10	Massachusetts	60.8	65.3	71.4	68.7	63.8	80.5	67.0
11	North Dakota	61.0	63.5	68.8	72.1	83.4	87.0	70.5
12	Rhode Island	61.1	62.1	62.3	61.8	64.3	59.7	62.0
13	Michigan	61.3	65.0	71.5	78.8	83.6	88.3	75.2
14	Colorado	61.5	63.2	61.2	66.1	70.0	69.8	64.7
15	West Virginia	63.2	64.2	58.0	56.0	63.7	67.6	63.5
16	Pennsylvania	64.0	65.6	71.7	77.8	85.5	86.9	74.7
17	New Jersey	64.5	67.5	68.1	66.0	71.3	76.0	67.8
18	Indiana	64.8	61.0	64.7	66.5	72.3	69.8	65.7
19	Maryland	65.3	64.2	64.5	63.9	64.9	77.7	64.7
20	South Carolina	65.4	67.9	66.5	68.7	70.1	71.1	68.3
21	Virginia	65.4	69.5	72.0	79.7	83.5	81.8	75.9
22	Alabama	66.2	66.9	70.1	73.9	75.1	79.4	72.0
23	Oklahoma	66.5	64.9	66.7	55.9	57.4	60.7	62.8
24	New Mexico	66.7	63.1	67.0	72.4	76.2	82.8	69.7
25	Vermont	69.2	70.2	72.5	74.6	72.8	87.8	72.7
26	Nevada	69.3	71.0	70.1	70.5	72.4	76.2	70.8

27	Ohio	71.9	65.1	67.8	67.2	66.8	86.0	67.5
28	Montana	73.3	63.9	66.3	70.0	74.3	83.4	71.7
29	Arizona	74.1	74.5	73.2	77.0	79.9	80.8	75.7
30	Arkansas	74.5	71.4	72.5	74.8	77.5	87.2	74.6
31	Minnesota	74.7	75.0	78.4	79.8	77.1	81.4	77.7
32	Utah	76.5	78.3	82.8	85.7	84.1	100.8	83.4
33	Missouri	76.6	78.0	81.9	77.0	79.4	82.9	78.7
34	California	76.9	77.4	78.4	80.7	86.6	87.6	79.5
35	Wyoming	78.7	79.6	83.0	85.9	88.8	79.3	81.3
36	Nebraska	79.2	78.2	81.9	83.8	87.9	92.0	82.8
37	Maine	79.6	79.1	80.2	70.4	72.6	79.7	79.3

Appendix C. The Likelihood function

Following Sims (1980), Equation (1) in 3.2 becomes:

$$Y = XA + E \quad (C1)$$

and

$$y = (I_m \otimes X)a + e, \quad e \sim 0, \Sigma_e \otimes I_T \quad (C2)$$

where Y and E are (4×4) matrices and X is a (4×1) matrix, $X_t = [y'_{t-1}, \dots, y'_{t-q}, \hat{y}'_t]$; y and e are (4×1) vectors, I_m is the identify matrix, and $a = \text{vec}(A)$ is a (4×1) vector.

Thus, the likelihood function of Equation (C2) is

$$\int (a, \Sigma_e) \propto |\Sigma_e \otimes I_T|^{-0.5} \exp\{-0.5(y - (I_m \otimes X)a)'(\Sigma_e^{-1} \otimes I_T)(y - (I_m \otimes X)a)\} \quad (C3)$$

where

$$\begin{aligned} & (y - (I_m \otimes X)a)'(\Sigma_e^{-1} \otimes I_T)(y - (I_m \otimes X)a) = \\ & (\Sigma_e^{-0.5} \otimes I_T)(y - (I_m \otimes X)a)'(\Sigma_e^{-0.5} \otimes I_T)(y - (I_m \otimes X)a) = \\ & [(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a]'(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a] \end{aligned}$$

and also

$$\begin{aligned} & (\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a \\ & = (\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols} + (\Sigma_e^{-0.5} \otimes X)(a_{ols} - a) \end{aligned}$$

where $a_{ols} = (\Sigma_e^{-1} \otimes X'X)^{-1}(\Sigma_e^{-1} \otimes X)'y$

Therefore we have

$$\begin{aligned} & (y - (I_m \otimes X)a)'(\Sigma_e^{-1} \otimes I_T)(y - (I_m \otimes X)a) = \\ & ((\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols})'((\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols}) \quad (C4) \end{aligned}$$

$$+ (a_{ols} - a)'(\Sigma_e^{-1} \otimes X'X)(a_{ols} - a) \quad (C5)$$

We derive the likelihood function of a VAR ($q=1$) as the product of a Normal density for a , conditional on the OLS estimate (i.e. a_{ols}) and on Σ_e , and a Wishart density for Σ_e^{-1} , conditional on a a_{ols} from the decomposition of Equation (C4) and Equation (C5) as follows:

$$\begin{aligned}
& \int (a, \Sigma_e) \propto |\Sigma_e \otimes I_T|^{-0.5} \exp\{-0.5(a_{ols} - a)'(\Sigma_e^{-1} \otimes X'X)(a_{ols} - a) \\
& -0.5(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols})'[(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols}]\} \\
& = |\Sigma_e|^{-0.5k} \exp\{-0.5(a_{ols} - a)'(\Sigma_e^{-1} \otimes X'X)(a_{ols} - a)\} \\
& \quad \times |\Sigma_e|^{-0.5(T-k)} \exp\{-0.5tr[(\Sigma_e^{-0.5} \otimes I_T)y \\
& \quad - (\Sigma_e^{-0.5} \otimes X)a_{ols})'[(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols}]]\} \\
& \propto \mathbb{N}(a|a_{ols}, \Sigma_e, X, y) \times \mathbb{W}(\Sigma_e^{-1}|y, X, a_{ols}, T - k - m - 1) \tag{C6}
\end{aligned}$$

where tr is the trace of the scale matrix $[(y - (I_m \otimes X)a_{ols})'(y - (I_m \otimes X)a_{ols})]^{-1}$.

The conditional posterior for a will be normal and the conditional posterior of Σ_e^{-1} will be Wishart.

Figure 1. Nominal yields on 10-year Treasury bonds and the federal funds target rate

Notes: The figure shows nominal yields from 1998 to 2013 on 10-year Treasury bonds for the U.S. and the federal funds target rate set by the Federal Open Market Committee. The data has been collected from Bloomberg database.

Figure 2. The average pension funds asset allocation

Note: The figure presents the asset allocation of pension funds for the following time-periods: from 1998–2013 (overall sample period), from 1998–2000 (period 1), from 2001–2006 (period 2), from 2007–2008 (period 3), and from 2009–2013 (period 4). The sample contains 151 pension funds from 50 states.

Figure 3. BVAR counterfactual analysis

Note: The figure shows the persistence of monetary policy shocks on pension funds risk-taking behavior. The actual return refers to the achieved investment return in pension assets from 1998 to 2013. Three scenarios are simulated, where the Treasury yield is higher by 100 basis points, 120 basis points, and 200 basis points, respectively, to assess the portfolio return.

OVERALL PANEL: PROBABILITY OF REGIME 1

SUB-PANELS: PROBABILITY OF REGIMES 1 -2 -3 -4

SUB-PANEL A

SUB-PANEL B

Figure 4. MS-SVAR switching regimes

Note: The figure illustrates the four Markov switching regimes, estimated using the MS-SVAR model. The Overall Panel exhibits the whole sample period and shows the identification of Regime 1. There are also four Sub-Panels which focus mainly on the period when the Regime is identified. Sub-Panel A shows regime 1 (1998–2000) where interest rates increased. Sub-Panel B displays regime 2 (2001–2006) where interest rates declined. Sub-Panel C exhibits regime 3 (2007–2008) where interest rates increased moderately. Sub-Panel D reveals regime 4 (2009–2013) where interest rates declined near the Zero Lower Bound.

Figure 5. Generalized impulse response functions to monetary policy shocks

Note: This figure depicts the generalized impulse response functions of the endogenous variables of the MS-SVAR model during four different monetary policy environments (Regimes 1, 2, 3, and 4 respectively). The four regimes represent the identification of the shocks (i.e. changes in the interest rates that lead to larger or smaller changes to bond yields). The figure summarizes responses by pension funds regarding the allocation of assets to government bonds and to equities following monetary policy shocks. The Y axis represents changes in the allocation and the X axis represents the time period. During Regime 1, the monetary policy shock causes a slight negative response to government bonds and a positive response (i.e. increase in the allocation) in equities. During Regime 2, when interest rates decline government bonds respond negatively (i.e. downward slope), while equities respond positively. During Regime 3, the monetary policy shock initially causes a negative response to the allocation of government bonds (downward slope), but later the response of government bonds recovers to higher levels, indicating allocation to bond assets increased slightly, which might be due to the increase in interest rates. On the contrary, the response of equities is initially positive, but later it becomes slightly negative. Finally, during Regime 4 (i.e. interest rates at historically low levels) the response of government bonds is overly negative, while allocation to equities increases substantially.

Figure 6. MS-SVAR counterfactual analysis

Note: The figure shows the persistence of monetary policy shocks on pension fund risk-taking behavior. The actual return refers to the achieved investment return in pension assets from 1998 to 2013. Three scenarios are simulated, where the Treasury yield is higher by 100 basis points, 120 basis points, and 200 basis points, respectively, to assess the portfolio return.

Table 1. Data analysis

This table presents the total number of state and local pension funds in the US. The number of states that is included in our sample is in parenthesis. Also, the table presents total assets for all the pension schemes (i.e. state and local) offered from each State, and assets that are included in our sample (i.e. assets in-sample). The total number of state pension plans is 224, while 151 are included in our sample. The total number of local pension plans is 3,761. Our sample contains the biggest pension plans by assets, and therefore it represents about 92% of the total assets of the public (state and local) pension fund industry. The source of this data is from the U.S. Census Bureau.

	State	State	Local	Total Assets	Assets in-sample
1	Alabama	4 (2)	6	\$ 33,251,180	\$ 31,688,375
2	Alaska	4 (2)	2	\$ 10,406,246	\$ 9,573,746
3	Arizona	4 (4)	3	\$ 41,443,164	\$ 40,655,744
4	Arkansas	6 (2)	27	\$ 22,219,051	\$ 19,019,508
5	California	5 (5)	58	\$ 657,647,900	\$ 639,233,759
6	Colorado	2 (2)	65	\$ 46,530,078	\$ 42,500,573
7	Connecticut	6 (3)	55	\$ 32,522,521	\$ 29,562,972
8	Delaware	1 (1)	7	\$ 8,642,790	\$ 8,020,509
9	Florida	1 (1)	471	\$ 163,785,916	\$ 138,890,457
10	Georgia	10 (8)	24	\$ 82,222,704	\$ 73,918,211
11	Hawaii	1 (1)	0	\$ 12,051,078	\$ 12,051,078
12	Idaho	2 (1)	2	\$ 12,272,952	\$ 11,413,845
13	Illinois	6 (5)	650	\$ 135,110,275	\$ 119,302,373
14	Indiana	8 (6)	61	\$ 28,263,756	\$ 25,550,435
15	Iowa	4 (2)	5	\$ 27,525,334	\$ 25,075,579
16	Kansas	1 (1)	7	\$ 15,918,274	\$ 14,660,730
17	Kentucky	6 (3)	15	\$ 28,043,843	\$ 25,211,415
18	Louisiana	14 (8)	21	\$ 39,936,873	\$ 34,026,216
19	Maine	1 (1)	0	\$ 11,432,765	\$ 11,432,765
20	Maryland	2 (1)	17	\$ 54,432,962	\$ 49,697,294
21	Massachusetts	14 (9)	86	\$ 64,984,732	\$ 58,746,198
22	Michigan	6 (5)	130	\$ 76,494,465	\$ 67,468,118
23	Minnesota	8 (4)	137	\$ 53,136,559	\$ 44,634,710
24	Mississippi	4 (2)	0	\$ 23,017,265	\$ 21,337,005
25	Missouri	10 (5)	56	\$ 58,748,518	\$ 51,169,959
26	Montana	9 (4)	0	\$ 9,060,965	\$ 7,819,613
27	Nebraska	5 (3)	8	\$ 12,748,146	\$ 11,090,887
28	Nevada	2 (2)	0	\$ 29,002,144	\$ 29,002,144
29	New Hampshire	2 (1)	2	\$ 6,450,662	\$ 5,812,046
30	New Jersey	7 (4)	3	\$ 74,449,190	\$ 66,706,474
31	New Mexico	5 (2)	0	\$ 23,139,872	\$ 19,946,570
32	New York	2 (2)	6	\$ 382,206,781	\$ 358,127,754
33	North Carolina	6 (6)	2	\$ 79,986,718	\$ 77,747,090
34	North Dakota	2 (2)	9	\$ 4,074,364	\$ 3,675,076
35	Ohio	5 (4)	1	\$ 159,749,953	\$ 142,337,208
36	Oklahoma	6 (3)	6	\$ 26,611,420	\$ 21,927,810
37	Oregon	1 (1)	5	\$ 59,390,416	\$ 54,639,183
38	Pennsylvania	3 (3)	1,577	\$ 95,888,331	\$ 80,450,310
39	Rhode Island	1 (1)	12	\$ 8,511,634	\$ 7,583,866
40	South Carolina	4 (3)	2	\$ 27,627,880	\$ 24,837,464

41	South Dakota	2 (1)	2	\$	9,571,530	\$	8,537,805
42	Tennessee	1 (1)	14	\$	45,050,770	\$	42,708,130
43	Texas	7 (7)	125	\$	213,473,749	\$	192,553,322
44	Utah	6 (3)	1	\$	22,991,422	\$	20,048,520
45	Vermont	3 (2)	2	\$	3,613,701	\$	2,901,802
46	Virginia	1 (1)	17	\$	70,627,037	\$	65,895,026
47	Washington	6 (6)	20	\$	65,919,198	\$	61,436,693
48	West Virginia	1 (1)	40	\$	12,330,864	\$	11,147,101
49	Wisconsin	1 (1)	2	\$	89,813,290	\$	87,388,331
50	Wyoming	6 (3)	0	\$	6,851,026	\$	5,713,756
		224(151)	3,761		\$3,279,182,264		\$3,014,875,552

Table 2. Descriptive statistics

This table presents the descriptive statistics for the 151 US pension funds from 50 states, with 2,416 observations. Panel A provides the summary statistics for pension plan return assumption, investment returns and the funding ratio, from 1998 to 2013. Panel B provides the summary statistics for the allocation of assets for the whole time period. The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Panel A: Pension funds characteristics.					
	Mean (%)	Standard deviation (%)	Minimum (%)	Median (%)	Maximum (%)
Return Assumption	7.86	4.19	5.75	8.00	9.00
1 Year Inv. Return	5.58	12.04	– 30.70	8.84	31.65
3 Years Inv. Return	5.22	6.27	– 13.70	5.21	17.90
5 Years Inv. Return	5.36	3.61	– 3.54	4.20	25.66
10 Years Inv. Return	6.87	2.54	– 1.47	7.20	13.90
Funding Gap Ratio	82.44	19.62	19.10	82.50	197.39

Panel B: Pension asset allocation, average for the overall sample period (1998-2013)					
	Mean (%)	Standard deviation (%)	Minimum (%)	Median (%)	Maximum (%)
Equities	53.87	12.27	0.00	56.10	75.40
Domestic Equities	36.21	12.42	0.00	38.50	71.57
International Equities	16.44	6.39	0.00	16.81	36.04
Bonds	27.32	9.70	0.00	26.30	100.00
US Govern. Bonds	25.98	11.31	0.00	25.00	100.00
International Bonds	2.44	2.41	0.00	0.30	9.90
Real Estate	6.07	4.15	0.00	5.96	28.40
Cash	2.44	2.99	0.00	0.17	22.50
Alternative Invest.	1.84	7.56	0.00	4.40	56.62
Pension Asset Beta	57.43	19.38	38.39	50.42	69.88

Table 3. Pension fund asset allocation

This table depicts the detailed asset allocation and the portfolio beta for 151 pension funds from 50 US States, with 2,416 observations. Panel A provides the allocation from 1998 to 2000. Panel B presents the allocation of assets from 2001 to 2006. Panel C shows the allocation of assets from 2007 to 2008 and Panel D exhibits the allocation of assets from 2009 to 2013. The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Panel A: Pension asset allocation, Period 1: 1998–2000					
	Mean (%)	St. deviation (%)	Minimum (%)	Median (%)	Maximum (%)
Equities	42.52	9.88	0.00	42.76	57.81
Domestic Equities	34.73	6.59	0.00	34.01	94.22
International Equities	7.79	3.82	0.00	4.28	19.35
Bonds	40.94	9.60	0.00	36.07	100.00
US Govern. Bonds	39.10	6.34	0.00	46.87	100.00
International Bonds	1.84	1.16	0.00	1.21	3.80
Real Estate	3.85	3.61	0.00	3.90	8.74
Cash	10.86	5.73	0.00	10.06	30.69
Alternative Invest.	1.83	2.04	0.00	1.62	8.77
Pension Asset Beta	48.46	10.53	0.00	44.93	56.25

Panel B: Pension asset allocation, period 2: 2001–2006					
	Mean (%)	St. deviation (%)	Minimum (%)	Median (%)	Maximum (%)
Equities	45.98	11.73	0.00	49.22	60.02
Domestic Equities	38.06	8.21	0.00	38.86	91.66
International Equities	7.92	5.05	0.00	9.40	25.80
Bonds	37.58	10.08	0.00	39.79	98.00
US Govern. Bonds	36.23	6.47	0.00	46.35	100.00
International Bonds	1.35	1.55	0.00	1.60	5.00
Real Estate	5.50	5.74	0.00	8.62	12.08
Cash	9.03	5.31	0.00	10.11	24.64
Alternative Invest.	1.91	2.26	0.00	1.64	10.93
Pension Asset Beta	50.96	12.07	0.00	46.83	60.30

Panel C: Pension asset allocation, period 3: 2007–2008

	Mean (%)	St. deviation (%)	Minimum (%)	Median (%)	Maximum (%)
Equities	50.02	11.98	0.00	52.76	72.40
Domestic Equities	32.07	10.36	0.00	40.45	79.82
International Equities	17.95	7.02	0.00	20.71	40.83
Bonds	33.06	9.98	0.00	30.60	100.00
US Govern. Bonds	32.50	5.31	0.00	30.05	100.00
International Bonds	0.56	1.07	0.00	0.24	4.00
Real Estate	8.45	6.03	0.00	6.29	33.56
Cash	6.02	2.21	0.00	6.84	14.77
Alternative Invest.	2.45	10.04	0.00	1.66	12.14
Pension Asset Beta	54.33	14.82	0.00	48.83	66.71

Panel D: Pension asset allocation, period 4: 2009–2013

	Mean (%)	St. deviation (%)	Minimum (%)	Median (%)	Maximum (%)
Equities	59.64	13.88	0.00	58.76	76.50
Domestic Equities	36.02	13.52	0.00	38.99	73.79
International Equities	23.62	8.93	0.00	23.01	42.87
Bonds	24.41	9.25	0.00	21.75	100.00
US Govern. Bonds	22.98	10.69	0.00	18.33	100.00
International Bonds	2.53	2.63	0.00	0.49	11.02
Real Estate	6.92	4.85	0.00	6.54	29.50
Cash	2.01	3.91	0.00	0.17	22.50
Alternative Invest.	6.35	6.40	0.00	6.12	59.84
Pension Asset Beta	68.81	15.39	0.00	49.02	74.09

Table 4. Top-fifteen pension funds by liabilities and funding coverage ratio

This table provides detailed characteristics for the top fifteen pension funds based on their liabilities (Panel A) and the fifteen best-funded pension plans (Panel B) as of 2013. In addition, it provides the 5- and the 10-year investment return, the percentage of assets allocated to equities and bond securities, and the systematic risk for each pension plan (i.e. portfolio beta). The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Panel A: Top-fifteen pension funds by liabilities							
Pension fund	Liabilities (U.S. \$)	Funding coverage ratio (%)	Inv. 5 year re- turn (%)	Inv. 10 year re- turn (%)	% of in- vestment in equities	% of invest- ment in bonds	Portfolio beta
California Teachers	222,280,992	67.0	3.72	7.53	53.6	16.79	0.57
Florida RS	154,125,952	85.4	5.04	7.44	59.09	22	0.62
Texas Teachers	150,666,000	80.8	5.4	7.2	49.7	14.3	0.64
New York State Teachers	94,538,800	87.5	5.2	7.5	58.89	18.99	0.52
Ohio Teachers	94,366,696	66.3	4.87	8.08	52.78	20.19	0.61
Illinois Teachers	93,886,992	40.5	4.2	7.2	43.9	24.79	0.60
Pennsylvania School Emp.	89,951,816	63.8	2.5	7.72	21.1	18.2	0.62
Wisconsin Retirement Sys	85,328,704	99.9	1.7	4.8	36.28	14.83	0.58
Virginia Retirement Sys	79,077,592	65.9	4	7.6	47.49	21.69	0.52
Georgia Teachers	72,220,864	81.0	6.27	6.55	73.5	26.49	0.56
Michigan Public Schools	63,839,728	59.5	6.8	7.4	41.79	12.1	0.62
North Carolina Teachers and State Employees	63,630,280	94.1	5	6.6	46.4	33.79	0.63
Oregon PERS	60,405,200	90.6	5	8.33	36.9	21.89	0.61
University of California	57,380,960	75.9	4.67	6.62	47.99	23.99	0.57
New Jersey Teachers	53,645,476	57.0	5.32	7.26	39.2	15.37	0.61

Panel B: Top-fifteen pension funds by funding coverage ratio							
Pension fund	Liabilities (U.S. \$)	Funding coverage ratio (%)	Inv. 5 year return (%)	Inv. 10 year re- turn (%)	% of in- vestment in equities	% of invest- ment in bonds	Portfolio beta
Washington LEOFF Plan 2	6,859,000	114.6	3.81	8.29	37.7	22.62	0.63
DC Police & Fire	3,644,085	110.09	7.19	6.8	52.99	28	0.65
Washington Teachers Plan	8,016,000	104.9	3.81	8.29	37.7	22.62	0.66
Washington PERS 2/3	23,798,000	102.3	3.81	8.29	37.709	22.62	0.60
Washington School Em- ployees Plan 2/3	3,273,000	101.9	3.81	8.29	37.7	22.62	0.62
South Dakota PERS	8,803,700	100	7.11	8.72	50.7	19.7	0.64
Wisconsin Retirement Sys	85,328,704	99.9	4.6	8.39	48.29	21.03	0.63
North Carolina Local Gov	20,338,784	99.8	5	6.59	46.4	33.79	0.65
TN Political Subdivisions	7,789,873	94.96	5.33	6.15	56.59	28.49	0.67
North Carolina Teachers and State Employees	63,630,280	94.19	5	6.59	46.4	33.79	0.69
TN State and Teachers	34,123,560	93.33	5.33	6.15	56.59	28.49	0.61
Louisiana State Parochial	3,217,464	92.5	13.65	7.28	37.4	26.71	0.67
Delaware State Employees	8,257,270	91.1	5.5	9.39	54.1	21.7	0.62
Oregon PERS	60,405,200	90.69	5	8.33	36.9	21.89	0.68
DC Teachers	1,759,043	90.09	7.2	6.8	52.99	28	0.67

Table 5. Relationship between lagged investment returns and Treasury yields on pension fund asset allocation

This table presents the results of the regression of the change in the percentage of allocation to bond securities, short-term cash and equity assets on the mean investment return per period. It also provides the change in the portfolio's beta and Treasury yield based on the percentage of changes in the allocation of assets, for 151 US pension funds from 50 States resulting in 2,416 observations. Panel A exhibits results for well-funded pension plans. In contrast, Panel B presents results for the most underfunded pension plans, from 1998 to 2013. The major data source is the Public Plans Database obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Panel A: Funding status decile 1 (best funding ratio)						
	Percentage of assets invested in bond securities and cash			Percentage of assets invested in eq- uities		
	Investment return (%)	Portfolio beta	Decline in treasury yield (%)	Investment return (%)	Portfolio beta	Decline in treasury yield (%)
Period 1: 1998–2000	–2.06	0.42	3.67	4.81	0.68	2.89
Period 2: 2001–2006	–3.03	0.57	6.81	6.94	1.73	7.22
Period 3: 2007–2008	–5.91	0.85	7.36	–0.87	1.06	6.36
Period 4: 2009–2013	–8.20	1.36	10.52	–2.39	0.41	7.61
Probability > χ^2	0.48	–	0.52	0.59	–	0.53
Pension funds	151	151	151	151	151	151
<i>R</i> –squared: Period 1	0.01	0.01	0.01	0.02	0.02	0.02
<i>R</i> –squared: Period 2	0.02	0.02	0.02	0.02	0.02	0.02
<i>R</i> –squared: Period 3	0.02	0.02	0.02	0.01	0.01	0.01
<i>R</i> –squared: Period 4	0.02	0.02	0.02	0.02	0.02	0.02

Panel B: Funding status decile 2 (worst funding ratio)						
	Percentage of assets invested in bond securities and cash			Percentage of assets invested in eq- uities		
	Investment return (%)	Portfolio beta	Decline in treasury yield (%)	Investment return (%)	Portfolio beta	Decline in treasury yield (%)
Period 1: 1998–2000	–1.90	0.31	2.04	2.66	0.49	1.80
Period 2: 2001–2006	–2.03	0.38	3.88	3.92	1.08	3.11
Period 3: 2007–2008	–2.97	0.40	5.92	1.80	0.53	4.87
Period 4: 2009–2013	–3.13	0.48	6.96	–0.94	0.21	5.05
Probability > χ^2	0.49	–	0.51	0.53	–	0.51
Pension funds	151	151	151	151	151	151
<i>R</i> –squared: Period 1	0.01	0.01	0.01	0.02	0.02	0.02
<i>R</i> –squared: Period 2	0.02	0.02	0.02	0.02	0.02	0.02
<i>R</i> –squared: Period 3	0.02	0.02	0.02	0.01	0.01	0.01
<i>R</i> –squared: Period 4	0.02	0.02	0.02	0.02	0.02	0.01

Table 6. Bayesian VAR counterfactual results

This table reveals the effects of monetary policy shocks on pension fund asset allocation decisions and risk-taking behavior. The time periods are split based on the drastic changes in monetary policy to capture the full effects and the changes in the characteristics of the pension funds. Three scenarios are simulated: i) 100 basis point increase in the Treasury yield; ii) 120 basis point increase in the Treasury yield; and iii) 200 basis point increase in the Treasury yield, for 151 US pension funds from 50 States, making 2,416 observations. The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Overall sample period (1998–2013)

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean	3.62	1.44	6.56	0.55
100bp	4.48	2.16	7.19	0.52
120bp	4.97	2.28	7.25	0.51
200bp	5.63	2.51	7.68	0.46

Period 1: 1998–2000

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean	5.03	3.01	7.86	0.49
100bp	5.92	3.85	8.51	0.45
120bp	6.06	3.97	8.64	0.44
200bp	7.01	4.30	9.28	0.40

Period 2: 2001–2005

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean	3.84	1.97	7.12	0.52
100bp	4.51	2.39	7.70	0.50
120bp	4.64	2.45	7.83	0.49
200bp	5.29	2.91	8.33	0.43

Period 3: 2006–2007

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean	2.97	1.29	5.87	0.57
100bp	4.48	2.16	6.51	0.53
120bp	4.97	2.28	6.70	0.52
200bp	5.63	2.51	7.49	0.48

Period 4: 2008–2013

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean	1.96	1.01	5.10	0.61
100bp	2.73	1.42	5.62	0.55
120bp	2.88	1.59	5.75	0.54
200bp	3.46	1.73	6.34	0.50

Table 7. Bayesian VAR estimation of portfolio effects with higher allocation of assets for bond securities

This table presents the effects of monetary policy shocks on pension fund asset allocation decisions and risk-taking behavior, based on the scenario that the allocation of assets in bond securities and short-term cash does not change from period 1 to period 4. The mean portfolio return represents 151 US pension funds from 50 States, making 2416 observations. The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Overall sample period (1998–2013).

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean return	3.62	1.44	6.64	0.55
100bp	4.48	2.16	7.48	0.51
120bp	4.97	2.28	7.57	0.50
200bp	5.63	2.51	7.86	0.45

Period 1: 1998–2000

Estimate	Bond securities (%)	Short-term Cash (%)	Portfolio total return (%)	Systematic risk
Mean return	5.03	3.01	7.86	0.49
100bp	5.92	3.85	8.51	0.44
120bp	6.06	3.97	8.64	0.43
200bp	7.01	4.30	9.28	0.38

Period 2: 2001–2005

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean return	3.84	1.97	7.53	0.52
100bp	4.51	2.39	7.91	0.50
120bp	4.64	2.45	7.94	0.49
200bp	5.29	2.91	8.52	0.42

Period 3: 2006–2007

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Mean return	2.97	1.29	5.91	0.57
100bp	4.48	2.16	6.77	0.52
120bp	4.97	2.28	6.82	0.51
200bp	5.63	2.51	7.62	0.47

Period 4: 2008–2013

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)	Systematic risk
Actual return	1.96	1.01	5.28	0.61
100bp	2.73	1.42	5.80	0.54
120bp	2.88	1.59	5.91	0.53
200bp	3.46	1.73	6.63	0.49

Table 8. Shocks, regimes and effects – MS-SVAR model

Regime/Shock	Effect on G. B yields	Effect on asset alloca- tion for G.B	Effect on allocation in equities/Alt. Inv.	Effect on portfolio risk
Peak level for I.R.	Positive ($>$)	Positive ($>$)	Negative ($<$)	Positive (lower risk)
Decrease in I.R.	Negative ($<$)	Negative ($<$)	Positive ($>$)	Negative (higher risk)
Moderate increase in I.R.	Slightly posi- tive ($\geq$)	Positive ($>$)	Slightly negative ($\leq$)	Positive (lower risk)
ZLB and QE	Negative ($<$)	Negative ($<$)	Positive ($>$)	Negative (higher risk)

Note: G.B. denotes government bonds, Alt. Inv. denotes alternative investments, I.R. is the interest rate, ZLB is the Zero Lower Bound level for the interest rate, and QE denotes the launch of unconventional monetary policy with the Quantitative Easing program.

Table 9. MS–SVAR counterfactual results

This table exhibits conditional forecasting for the effects of monetary policy shocks on pension fund asset allocation decisions and risk-taking behavior. The time periods are divided based on the drastic changes in monetary policy to capture the full effects and the changes in the characteristics of pension funds. Three scenarios are simulated: i) 100 basis point increase in the Treasury yield; ii) 120 basis point increase in the Treasury yield; and iii) 200 basis point increase in the Treasury yield, for 151 US pension funds from 50 States, making 2416 observations. The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Overall sample period.

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	3.62	1.44	6.56
100bp	4.51	2.19	7.23
120bp	4.98	2.28	7.29
200bp	5.72	2.59	7.74

Period 1: 1998–2000

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	5.03	3.01	7.86
100bp	5.98	3.87	8.54
120bp	6.11	3.99	8.67
200bp	7.16	4.38	9.35

Period 2: 2001–2005

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	3.84	1.97	7.12
100bp	4.63	2.48	7.89
120bp	4.69	2.51	7.92
200bp	5.40	3.01	8.55

Period 3: 2006–2007

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	2.97	1.29	5.87
100bp	4.53	2.18	6.54
120bp	4.98	2.28	6.72
200bp	5.72	2.59	7.60

Period 4: 2008–2013

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Actual return	1.96	1.01	5.10
100bp	2.79	1.44	5.68
120bp	2.90	1.61	5.77
200bp	3.55	1.76	6.48

Table 10. MS-SVAR estimation of portfolio effects with higher allocation of assets for bond securities

This table presents the effects of monetary policy shocks on pension fund asset allocation decisions and risk-taking behavior based on the scenario that the allocation of assets in bond securities and short-term cash does not change from period 1 to period 4. The mean portfolio return represents 151 US pension funds from 50 States, making 2,416 observations. The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Overall sample period.

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	3.62	1.44	6.70
100bp	4.51	2.19	7.53
120bp	4.98	2.28	7.59
200bp	5.72	2.59	7.92

Period 1: 1998–2000

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	5.03	3.01	7.86
100bp	5.98	3.87	8.54
120bp	6.11	3.99	8.67
200bp	7.16	4.38	9.35

Period 2: 2001–2005

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	3.84	1.97	7.58
100bp	4.63	2.48	7.94
120bp	4.69	2.51	7.97
200bp	5.40	3.01	8.61

Period 3: 2006–2007

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Mean return	2.97	1.29	5.95
100bp	4.53	2.18	6.79
120bp	4.98	2.28	6.83
200bp	5.72	2.59	7.84

Period 4: 2008–2013

Estimate	Bond securities (%)	Short-term cash (%)	Portfolio total return (%)
Actual return	1.96	1.01	5.33
100bp	2.79	1.44	5.84
120bp	2.90	1.61	5.92
200bp	3.55	1.76	6.68

Table 11. Marginal log-likelihood for 5.000 simulations

This table displays results for bridge sampling and Chib's method for the marginal likelihood value for bridge sampling and Chib's method. The shortest distance from zero indicates the most appropriate the number of regimes. The most suitable number of regimes appears in **bold**. The sample period is from 1998 to 2013 and contains a total of 2416 observations. The major data sources are the Public Plans Database, obtained from the Center for Retirement Research at Boston College and the Bloomberg database.

Filtered probability of regimes	1	2	3	4	5
Overall sample					
Bridge sampling	-853.82	-844.76	-833.09	-822.23	-829.70
Chib	-849.21	-841.04	-831.71	-820.85	-830.63
Period 1					
Bridge sampling	-938.03	-930.60	-920.33	-909.75	-921.44
Chib	-936.42	-931.93	-921.15	-910.06	-919.10
Period 2					
Bridge sampling	-855.73	-849.01	-840.19	-829.37	-840.62
Chib	-842.88	-834.26	-824.25	-813.65	-824.77
Period 3					
Bridge sampling	-972.11	-963.08	-953.02	-941.24	-951.94
Chib	-956.07	-947.63	-937.19	-926.16	-935.29
Period 4					
Bridge sampling	-968.79	-960.48	-950.42	-939.92	-948.67
Chib	-951.40	-943.85	-934.16	-923.10	-931.80