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Abstract

US public pension funds deficits remain stubbornly high even though market conditions have improved in the post-crisis period. This article examines the role of lower short- and long-term interest rates imposed by the use of unconventional monetary policy on pension funds risk taking and asset allocation behavior. We quantify the effects of the Zero Lower Bound policy and the launch of unconventional monetary policy measures by using two structural Vector AutoRegression (VAR) models, a Bayesian VAR and a Markov switching-structural VAR. We provide the first comprehensive evidence showing that persistently low interest rates and falling Treasury yields cause a substantial increase in pension funds risk and portfolios beta. Additionally, we document that the severe funding shortfall in many pension schemes is, to a large extent, associated with and prompted by changes in the monetary policy framework.

JEL classification: G23; E52; G11.

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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, underfunding pension obligations has been a credit pressure and a key to a broader retirement crisis. The rise in life expectancy, which increases liabilities in a significant manner (Brown et al., 2005; Cocco and Gomes 2012), and the immense challenges in the asset allocation landscape, render the financing of these liabilities more difficult than ever (Cocco et al., 2005; Franzoni and Marin, 2006). 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.[1] 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.[2] 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. Lucas and Zeldes (2009) show that 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 at a rate that reflects the risk of the liabilities. Novy-Marx and Rauh (2011) 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.[3] Evidently,

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[1] This figure is obtained using the calculation and actuarial method of the US Census Bureau.
[2] Please, see, Appendix B for a detailed presentation of the most underfunded state pension plans.
[3] 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

US public pension funds have been investing an ever-increasing proportion of their assets in risky investments (Andonov et al., 2014) and equities (Rauh, 2009).[4] The latter author finds that 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 and real estate investment trusts, to achieve higher returns and to implement efficient risk management.

This strategy stands in contrast with the traditional framework developed in the pioneering works of Black (1980), Tepper (1981), Bodie (1990), and Brown and Wilcox (2009), who find that pension funds achieve shareholder wealth maximization by investing entirely in bonds. Additionally, risky investments make the potential impact of shocks more persistent and apparent. At the same time, over the last two decades, the US monetary policy framework has moved radically into an era with lower policy rates close to the Zero Lower Bound. With single 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 on the open market 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, 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 in several countries (see, e.g., Kapetanios et al., 2012; Joyce et al., 2012; Chen et al., 2012; Gambacorta et al., 2014).

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over a time period of 30 years, while the higher the assumed invested return, the lower the required contribution by pension fund members.

[4] In the United States, the Public Fund Boards, which govern public pension funds, decide on the allocation of assets. To the extent that they 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.

The above-mentioned changes in monetary policy create an incentive for pension funds to invest their assets in risky securities. 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.[5] Motivated by the importance of the research question and the lack of empirical evidence on the role of monetary policy changes in pension fund strategies, we examine these challenging issues by addressing the following four questions: i) What is the effect of unconventional monetary policy on pension fund risk and asset allocation decisions? ii) Is there a correlation between asset allocation and short-term lagged investment returns? And if so, what is the effect of unconventional monetary policy on this correlation? iii) Which of the two arguments, risk shifting or risk management incentives, dominates the risk-taking behavior of pension funds?

To assess the impact of monetary policy changes on pension funds, we initially use a regression analysis to identify how asset allocation changes over time.[6] We then 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

[5] Building on the asset substitution problem (Jensen and Meckling, 1976), risk-management incentives are defined as changes in the allocation of assets that result in a decrease in the risk level of the portfolio (i.e. portfolio beta drops). Risk-shifting incentives are changes in the allocation of assets that increase the risk level of the portfolio (i.e. portfolio beta rises). For Rauh (2009, p.2689), when changes in the allocation of assets cause a drop in the riskiness of pension funds' portfolios, then these changes have a risk-management incentive.
On the contrary, when changes in the allocation of assets lead to an increase in the riskiness of pension funds' portfolios, then these changes have a risk-shifting incentive.

[6] As in Kapetanios et al. (2012), changes in the monetary policy that lead to larger or smaller changes in yields are called monetary policy shocks. The underlying structural shocks are identified through restrictions on the impulse responses.

interconnections between Treasury yields, interest rates, and asset and risk management decisions. Further, 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 (Waggoner and Zha, 2003; Primiceri, 2005). The use of different models that vary in their emphasis increases the robustness of our findings. We also use these models to conduct a counterfactual analysis to show that interest rates, and hence 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 spreads and interest rates proposed by Estrella (2005). The counterfactual approach used in this paper is similar in spirit to Kapetanios et al. (2012).[7]

The results of our study indicate that the new monetary policy era prompted a gradual increase in pension fund risk-taking behavior. Additionally, risk-shifting incentives to avoid low-return investments (such as Treasury bonds) in favor of more risky investments (such as equities and alternative assets) dominate the pension fund asset allocation decisions. More precisely, in an important departure from prior studies, we separate our sample into different time periods to capture the effect of variations in monetary policy 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 that higher returns precede higher equity allocation. This finding indicates that asset allocation is determined by risk-management incentives. Conversely, the results for the sub-periods uncover the absence of correlation between asset allocation and short-term lagged investment returns since 2007–2008, which implies that the risk-management incentive is not the primary reason for the reduced allocation to Treasury bond investments in pension funds.

[7] Additional information on this approach is provided in Section 3.2.

If risk management is not the reason why pension funds decrease their investments in safe assets and increase their allocations to equities and alternative assets, then what is? While the variation in pension fund asset allocation remains unexplained by the existing empirical literature, we find a positive correlation between risk taking and the decline in Treasury yields, which is consistent with a risk-shifting incentive. In particular, we uncover that 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. As a result, changes in monetary policy associated with lower interest rates, unconventional measures, and lower bond yields trigger substantial increases in pension funds risk taking and meaningful changes in asset allocation, in favor of risky investments.

Further results from the counterfactual analysis of the effects of unconventional policies using the BVAR model suggest that, without significant declines in Treasury yields and the launch of asset purchases, 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 percentages for assets allocated to bonds. Notably, in many cases, the assumed higher level of interest rates would have helped funds to achieve their planned return of 8%. Simultaneously, portfolio risk would have been substantially lower. Therefore, the introduction of unconventional monetary policy prompts 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 severely affected by the new monetary policy framework. In particular, annual investment return increases significantly from 6.56% to 7.74%.

If Treasury bonds offer an opportunity for significantly lower investment risk, what causes the risk-shifting incentive? Our findings provide a plausible explanation and offer strong support for our conjectures. More precisely, the results suggest that pension plans assume an unrealistically high expected rate of return, which they fail to reach on average. Indeed, 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. Evidently, a low level of interest rates drives returns much lower than expected, while crashes in the stock markets, such as that experienced in 2001 and the financial meltdown of 2007–2008, meaningfully depress fund assets.

This study makes an important contribution to our understanding of the determinants of pension fund risk-taking behavior. It is the first study to explicitly account for exogenous factors that contribute to pension fund risk behavior. Specifically, the critical role of unconventional monetary policy is amplified as an important component of pension plans. Second, it provides new evidence on the effects of monetary policy changes on pension fund asset allocation decisions, shedding new light on the determinants of pension plan risk taking. For instance, rock-bottom interest rates are inflicting increasing pain on pension funds, making the challenge of generating adequate investment returns particularly acute. However, too much exposure to investments with potentially higher-return but more volatility, such as equities, jeopardizes the ability of funds to keep promises to pensioners. Third, it contributes to the debate on the dominant role of risk-shifting and risk-management incentives on pension plan asset allocation.

Our study is related to the work of Leland (1998), Rauh (2009), and Mohan and Zhang (2014), who examine the determinants of pension fund risk-taking behavior. Empirical evidence on the dominance of risk shifting in pension funds risk-taking behavior is particularly thin. Specifically, Rauh (2009) finds no evidence that pension funds, and particularly financially distressed funds, engage in risk-shifting behavior. On the contrary, he documents a correlation between asset allocation and lagged investment returns, implying that changes in the allocation of assets are prompted by an incentive for efficient risk management. Leland (1998) assumes that pension funds cannot commit to pension beneficiaries and hence take risks with their assets, prompting risk-shifting behavior. Similarly, Mohan and Zhang (2014) suggest that public funds undertake more risk when underfunded, consistent with the risk transfer hypothesis. We update their work by using a comprehensive sample of public pension funds, offering new evidence on the dominant incentives for risk shifting prompted by loosening monetary conditions, and providing the first comprehensive findings on the critical role of unconventional monetary policy.

The remainder of this paper proceeds as follows. Section 2 discusses the relevant literature. Section 3 develops the hypotheses and describes the methodology. Section 4 depicts the dataset and analyses the results. Section 5 presents robustness checks and Section 6 concludes.

2. Literature review

Blake et al. (2013) document that, over the past two decades, pension funds have increased the proportion of their assets invested in equities and alternative investments such as real estate, and private equities. However, traditional economic theory contradicts this development, suggesting that asset allocations and liability discount rate choices should be more conservative as a fund matures (see, e.g., Benzoni et al., 2007; Lucas and Zeldes, 2009). Therefore, future streams of pension payments should be discounted at a rate that reflects their intrinsic riskiness. Specifically, the covariance with priced risks should make pension payments certain and minimize the systemic risk. In particular, Black (1980), Tepper (1981), Bodie (1990), Bader and Gold (2007) show that pension funds maximize shareholders value by investing entirely in fixed income securities. Bond securities should also, in theory, be a dominant part of pension fund strategic asset allocation, for the purposes of optimal risk management. Is change in asset allocation an incentive for higher risk (i.e., risk shifting) or a more efficient way of risk management?

The changes in asset allocation do not indicate that fund managers achieve an optimal asset portfolio, because asset allocation decisions depend on developments in the economic and financial environment. These developments become increasingly important for long-term investors, such as pension funds (Campbell and Viceira, 2002, Chapter 1). Therefore, our study explores only the incentive for changes in the riskiness of assets. For instance, the solution to a multiperiod portfolio choice problem can be very different from the solution to a static portfolio choice problem (Campbell et al., 2003). Hence, we are not judging the importance of an asset class to derive an optimal portfolio that is hedged to generate the most efficient funds at minimum risk (Cochrane, 2014).

Boards of pension funds have an incentive to postpone the difficult decisions to restructure an underfunded pension plan, and therefore prefer to transfer the funding risk to future generations. The existing literature presents three explanations for the major shift toward risky assets by US public pension funds: i) An incentive created by existing regulatory conditions; ii) an incentive for risk management; and iii) an incentive for risk shifting behavior. Given that underfunded pension funds face fiscal constraints, they have an incentive to postpone decisions on increased contributions (or decreased pension benefits), taking advantage of the existing regulatory framework. Lucas and Zeldes (2009) show that the accounting rules for public pension funds 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 at a rate that reflects the risk of liabilities. Accordingly, public pension funds have incentives to increase their investment in risky assets to achieve higher investment returns.

By contrast, Leland (1998) and Mohan and Zhang (2014) argue that the incentive for risk shifting (and thus higher performance) is the factor that dominates the pension fund decision to move towards risky investments rather than the quest for effective risk management. In particular, Leland (1998) assumes that pension funds take risks with their assets, prompting a risk-shifting behavior. In a similar vein, Mohan and Zhang (2014) suggest that public funds undertake more risk when underfunded, consistent with the risk transfer hypothesis. Our study contributes to the debate on the causes of risk-taking and on the dominant role of risk-shifting incentives for pension plans asset allocation.

Rauh (2009) examines the investment policy implications of corporate pension plans in the United States and finds that well-funded pensions take more risk while underfunded pensions are more risk-averse. This author also documents that: i) pension plans are more heavily invested and allocated in risky securities, and ii) the positive relationship between investment lagged returns and equities is prompted by risk-management incentives, which seems to be consistent with the view that heavy asset allocations to risky securities promote efficient risk management. 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 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.

3. Methodological framework

3.1 Hypothesis development

The traditional theoretical framework argues that pension funds fulfil shareholder wealth maximization by investing entirely in bonds (see, Black, 1980; Tepper, 1981; Bodie, 1990). Under this framework, bond-related investments (i.e., riskless securities) are supposed to minimize associated pension fund portfolio risk while achieving a return higher than the inflation rate. As a result, pension fund strategic asset allocation must be dominated mainly by investments in bond securities. 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. However, over the last decades, the proportion of pension fund assets invested in risky securities, such as equities and alternative investments, has increased considerably (Rauh, 2009; Blake et al., 2013; *inter alia*). Benzoni et al. (2007), and Lucas and Zeldes (2009) provide a plausible explanation for this incentive by arguing that the distinctive regulations for US public pension funds link the choice of their liability discount rate to the expected rate of return on their assets rather than to the riskiness of their assets. Risky investments offer a higher expected return and, hence, high liability discount rates. This allows pension funds to present lower degrees of underfunding and therefore to camouflage their shortfalls. In addition, the introduction of a loose monetary policy in accordance with other unconventional monetary tools should create an incentive for pension funds to invest their assets in risky securities. We build on these elements to hypothesize that

Hypothesis 1: The incentive for risky investments is determined by the decline in interest rates and the launch of unconventional monetary measures.

Moreover, as proposed by Rauh (2009), a risk management perspective 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. On the contrary, as discussed in Leland (1998), underfunded plans prefer to increase the percentage of assets invested in risky securities instead of requiring increased contributions. These contradictory arguments prompt us to examine the following hypothesis

Hypothesis 2: Changes in the behavior of pension funds are driven by risk-shifting or risk-management incentives

To assess these hypotheses and to capture the impact of changes in the monetary policy framework, we split our sample data into four periods: i) Period 1 (1998–2000) when 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 decline of the interest near the Zero Lower Bound, while the US Federal Reserve announced a large program of asset purchases and other unconventional monetary measures. In addition, we examine several scenarios in which monetary policy changes are less persistent to investigate the effects on portfolio risk (i.e., beta) and the allocation of assets to risky investments.

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 changes on the risk-taking behavior of pension funds. We also conduct a counterfactual analysis with respect to monetary policy changes. 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 changes on macroeconomic variables. Motivated by these studies, we build a similar BVAR-based model

$$Y_t = \Theta_0 + \Theta_1 Y_{t-1} + \cdots + \Theta_p Y_{t-p} + e_t \quad (1)$$

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.[8] Hence, the expected value of the matrix Θ_1 is $E(\Theta_1) = 0.99 \times I$. We assume that Θ_1 is normal conditionally on Σ, with first and second moments given by

$$E\left[\Theta_1^{(ij)}\right] = \begin{cases} 0.99 & if\ i=j \\ 0 & if\ i \neq j \end{cases}, Var\left[\Theta_1^{ij}\right] = \varphi\sigma_i^2 \;/\; \sigma_j^2 \quad (2)$$

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 $E(\Sigma) = diag(\sigma_1^2, \ldots, \sigma_N^2)$. Our BVAR model is similar to Bańbura et al. (2010) and Kapetanios et al. (2012) in that it is estimated using rolling windows to account for structural changes in monetary policy. Conse-

[8] 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 to R(α)=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: $T(ln|\Sigma_e^{re}| - ln|\Sigma_e^{un}|) \xrightarrow{D} x^2(v)$, where $X_t = y'_{t-1}, \ldots, y'_{t-q})'$, and $X' = X_0, \ldots, X_{T-1})$, is a (4×4) matrix (i.e. mq*T) and $v = 2$, which represents the number of restrictions.

quently, 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 several regimes: (i) relatively high interest rates between 1998 and 2000 (regime 1); (ii) the stock market crash of 2001 (regime 2), which led to a dramatic decline in interest rates; (iii) the 2007 to 2008 period, in which the federal funds target rate increased modestly (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 to near the Zero Lower Bound and introduced unconventional monetary measures (i.e., quantitative easing) to promote financial stability and economic development in the U.S. This pattern of frequent changes in the US monetary policy over recent years led us also 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

$$Y_t = c_s + \sum_{j=1}^{k} B_{j,S} Y_{t-j} + A_{0,S}\varepsilon_t \tag{6}$$

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.[9]

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

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

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

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

[9] Note again 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.

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 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 techniques estimate the full probability model and contain a decision theoretic foundation, allowing us to reach a sound solution. Bayesian inference includes uncertainty in the probability model, yielding more realistic suggestions. Also, our structural models employ prior distributions; 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 without monetary policy changes, 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 long-term government bond yields. We simulate two scenarios: (i)

Monetary policy interventions cause a downward shift in Treasury yields; and (ii) monetary policy does not change over time, and hence Treasury yields are higher, which is contrary to scenario (i). Scenario (i) mimics the real monetary policy adopted by the Federal Reserve while capturing the effect of unconventional policies on pension fund asset allocation decisions. Accordingly, scenario (ii) assumes that 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 changes, we compare the effect of the two scenarios on pension fund performance.

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. In a similar vein, Christensen and Rudebusch (2012) find that government bond yields declined, following announcements by the Federal Reserve and the Bank of England of plans to buy long-term debt. Also, Weale and Wieladek (2016) use a Bayesian VAR model and document that 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 U.S. and the U.K., 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 Bond yields would have been higher in a different monetary policy framework.

4. Empirical results

4.1 Data 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 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).[10] 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% in 2012. Similarly, the federal funds rate decreased from 6.5% in 2000 to 0.25% in 2013.

"Please insert Figure 1 about here"

Table 1 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. A value of the ratio 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 allocations for the pension funds and the estimated betas (i.e., the systematic risk) 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

[10] Please, see, Appendix A for detailed information on the variables used in the analysis.

assumption within and across pension funds. This assumption makes it clear that, if interest rates are below 5%, all investments allocated to government bonds and cash will underperform on a yearly 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 70.0%–90.0%. The minimum (19.6%) and the maximum (197.3%) ratios suggest a high variability of pension funding status. Further, 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 1 about here"

Table 2 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, 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 lowered its policy rates to close to the Zero Lower Bound and announced a large program of asset purchases, confirming that unconventional monetary measures triggered an incentive for riskier investment (i.e. confirming Hypothesis1). 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 with 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' allocations.

Moreover, Panel A of Table 2 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, indicating that changes in monetary policy depressed pension fund assets.

"Please insert Table 2 about here"

Panel A of Table 3 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 3 about here"

4.2 Risk determinants of asset allocation

To shed light on the determinants of pension fund asset allocation, we examine its relationship with: i) the return on pension assets during the fiscal year; ii) the portfolio's market risk (beta); and iii) changes in monetary policy represented by significant declines in Treasury bond yields. Table 4 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 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 subsequently increases the systematic risk of the portfolio by 0.68%.

We also find that a similar correlation exists during period 2, where again, a 10% increase in 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-averse behavior. However, in periods 3 and 4, a 10% increase in investment return prompts a decline in the percentage of assets allocated to equities, indicating that pension funds allocate a significant proportion of assets to alternative investments. The effect of lagged returns is statistically significant at the 5% level. As a result, 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 short-term 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 4. 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 apparent. 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 4 about here"

Overall, our results, which are consistent with the patterns shown in Figures 1–2 where a decline of 5% points 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, indicate that pension investment behavior is best characterized by the risk-shifting hypothesis (i.e. Hypothesis 2). That is, 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. Our simulations are based on the empirical findings in Kapetanios et al. (2012), which suggest that the use of unconventional monetary policy tools, from 2008 until 2011, may have depressed government bond yields by about 100 basis points. Accordingly, we assume that government bond yields would have been 100 basis points higher in our sample period. To assess the impact of monetary policy changes on the asset allocation 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 changes) and take the difference between the two as our estimate. Moreover, we increase the allocations to government bonds and decrease the allocations 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 initiatives 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 5 reports the estimated effects of changes in monetary policy on pension fund investment return and asset allocation. The mean return results reveal that the decrease in Treasury bond yields, following the change in monetary policy, substantially decreased the return on bond investments, making these investments unattractive. The largest impact from monetary policy changes 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%. There is clearly a risk-shifting incentive to riskier securities, such as equities and alternative investments, in hedge funds and private equity 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 the 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 5, 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 funds achieve their planned return of 8%. Figure 3 evidences the difference in return under the three counterfactual scenarios under which the percentage of pension fund assets allocated to equities could be lower since investments in safer assets would be more attractive.

"Please insert Table 5 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 6 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 6 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 7 identifies monetary policy shocks through the changes in the interest rates. In particular, Table 7 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 the short-term rate is expected to cause a compression in the yield curve. On the other hand, a negative shock is expected to trigger an increase in the yield curve.

"Please insert Table 7 about here"

"Please insert Figure 4 about here"

Figure 5 shows the impulse response functions to Treasury bonds and equity allocation following a shock to monetary policy. 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 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. These results imply that the monetary policy framework dominates risk shifting considerations and they confirm our hypothesis that the incentive for risky investments is determined by a decline in interest rates and the launch of unconventional monetary measures.

"Please insert Figure 5 about here"

To capture the effects of monetary policy changes, 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 8 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 funds achieve their planned return of 8% (in periods 1 and 2). Moreover, the MS-SVAR model indicates that if monetary policy changes had been less persistent, the portfolio risk (i.e., beta) would be smaller and the allocation to bond securities meaningfully higher.

"Please Insert Table 8 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 9, 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 9 about here"

4.5 Policy implications

The US monetary policy framework has undergone dramatic changes over recent years. Short-term nominal interest rates decreased to near the Zero Lower Bound to overcome the stock market crash of 2001 and the subprime crisis and financial turmoil of 2008. Our results constitute sufficient evidence that monetary policy shocks prompted risk-shifting incentives in US public pension funds, pushing the funds to allocate a larger proportion of their assets to risky investments as interest rates declined. This confirms our hypotheses that the loosening of the monetary policy framework deteriorated the allocation of assets and provoked a shift in pension fund risk incentives. Moreover, our findings reveal that the source of variation in asset allocation can be clearly attributed to shocks to Treasury yields. Evidently, rock-bottom interest rates are inflicting increasing pain on pension funds, which makes the challenge of generating an adequate investment return particularly acute. Similar results from our BVAR and MS-SVAR models suggest that the unprecedented decline in interest rates caused an underperformance of 130 and 146 basis points annually, respectively.

Simultaneously, US public pension funds responded to these changes with a shift toward more risky investments, such as equities, private equity, real estate, and other alternative assets, to achieve the high benchmark rate of return on their assets. This allows pension funds to present lower degrees of underfunding, to mask their shortfalls, and therefore, to delay difficult decisions on contribution levels and pension benefits. Currently, fund managers have an incentive to postpone painful decisions, to restructure underfunded pension plans; they prefer to transfer the funding risk to future generations. Nevertheless, too much exposure to investments with potentially higher return but more volatile investments, such as equities, jeopardizes promises to pensioners, as it is evident from the 2001 and 2008 stock market crashes. As a result, a safety-first investment strategy, in which pension funds allocate a higher proportion of their assets to low-yielding securities such as Treasury bonds, seems to be a good –though relatively difficult to be implemented– alternative, particularly during turbulent financial periods.

Moreover, a change in pension funds' unrealistic assumptions about future investment returns could help mitigate the problem of underfunding. For instance, if the assumption was a 5% investment return instead of 8%, then pension schemes would change the contribution required by (or the benefit distributed to) each member, to close the existing deficit over an acceptable time horizon. Additionally, the results provide ample evidence that deficits remain stubbornly high, although in the post-crisis (2008) period, market conditions have improved. Another potential reason for the deficit is that pension funds are not efficiently hedged for interest rate and inflation risk, which requires effective interest rate and inflation-hedging strategies to mitigate the problem. Finally, a plain vanilla strategy using easy redemption options could mitigate the risk of a severe crash in the stock market and as a result minimize pension funds' portfolio risk. In particular, an easy redemption option could be very effective in mitigating redemption pressures during stress periods in the markets.

5. Robustness check

The main finding of our study is that the Zero Lower Bound policy and the launch of a large program of asset purchases (i.e., quantitative easing) triggered a risk-shifting behavior for pension funds to invest in riskier securities, such as equities and alternative investment assets. Allocations of assets to government and Treasury bonds decreased meaningfully as pension funds looked for 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 approach 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.[11] A high value of the log-likelihood (i.e., a value closer to zero) indicates better fitting. Table 10 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 10. The increased value in regime 5 implies that the four-regime model fits the data best.

"Please insert Table 10 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

[11] The marginal likelihood can be computed in Markov-switching models in a similar way to Hamilton and Susmel (1994).

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 for US public pension funds. In particular, since 2007, asset allocation has not been correlated with short-term lagged investment returns. As a result, the incentive for risk management is not the primary reason for the reduced allocation of Treasury bond investments in pension funds. On the contrary, there is positive correlation between risk taking and the decline in Treasury yields, suggesting the presence of an incentive for risk shifting.

This study also examines pension fund risk-taking behavior and variation in asset allocation by quantifying the effects of monetary policy shocks. Our empirical analysis is based on a Bayesian VAR model and a Markov-switching structural VAR model. The latter typically 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 show that 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%. As a result, changes in monetary policy associated with lower interest rates, unconventional measures, and lower bond yields trigger a substantial increase in pension funds risk-taking and meaningful changes in asset allocation in favor of risky investments.

Interestingly, we find consistent results on the reaction of pension fund investment return to monetary policy changes, whatever the model used. Indeed, 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 yield using the BVAR approach, and from 6.56% to 7.74% for a 200-basis-point increase in 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).

In response to the questions raised in the introduction, we find that: (i) changes in monetary policy (i.e., low interest rate environment and unconventional monetary measures) lead to the adoption of risky strategies by pension funds and to meaningful changes in asset allocation; (ii) without the significant decline in Treasury yields, portfolio risk would be substantially lower, as documented by the counterfactual scenarios, while the assumed rate of return would also be meaningfully higher and closer to the average pension plan benchmark target of 8%; and (iii) the lowering of policy rates close to the Zero Lower Bound, caused a risk-shifting incentive to riskier securities such as equity and alternative investments in hedge funds and private equity.

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Appendix A: Data Analysis

In the U.S., 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 U.S. 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. 84 pension systems (out of a total of 151) have one pension plan, and the rest have more than one pension plan.

The major data source for the study is the Public Plans Database (PPD) obtained from the Center for Retirement Research at Boston College[12]. 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.

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	Colorado Municipal
Colorado School	Colorado State	Connecticut SERS
Connecticut Teachers	Contra Costa County	DC Police & Fire
DC Teachers	Delaware State Employees	Denver Employees
Denver Schools	Duluth Teachers	Fairfax County Schools
Florida RS	Georgia ERS	Georgia Teachers
Hawaii ERS	Houston Firefighters	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

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

Louisiana Teachers	Maine Local	Maine State and Teacher
Maryland PERS	Massachusetts SERS	Massachusetts Teachers
Michigan Municipal	Michigan Public Schools	Michigan SERS
Minneapolis ERF	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 Mexico PERF	New Mexico Teachers
New York City ERS	New York City Teachers	New York State Teachers
North Carolina Local Government	North Dakota PERS	North Dakota Teachers
NY State & Local ERS	NY 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	Rhode Island Municipal	San Diego County
San Francisco City & County	South Carolina Police	South Carolina RS
South Dakota PERS	St. Louis School Employees	St. Paul Teachers
Texas County & District	Texas ERS	Texas LECOS
Texas Municipal	TN Political Subdivisions	TN State and Teachers
University of California	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 Virginia Teachers	Wisconsin Retirement System
Wyoming Public Employees	Arizona State Corrections Officers Retirement Plan {CORP}	Connecticut Municipal Employees Retirement System {MERS}
Iowa Municipal Fire and Police Retirement System {MFPRSI}	Louisiana Municipal Police Employees Retirement System {MPERS}	Louisiana School Employees Retirement System {LSERS}
Louisiana State Parochial Employees Retirement System {PERS}	Minnesota Public Employees Retirement Association {MPERA}[Police and Fire Retirement Fund]	Oklahoma Police Pension and Retirement System {Police System}
Utah Public Safety	Alameda County Employee's Retirement Association {ACERA}	Kern County Employees Retirement Association {KCERA}
Los Angeles City Employees Retirement System {LACERS}	Los Angeles Fire and Police Pension System {Pensions}	Los Angeles Water and Power Employees Retirement Plan {DWP}
Orange County Employees Retirement System {ERS}	Sacramento County Employees Retirement System {The System}	San Diego City Employees Retirement System {SDCERS}
Chicago Municipal Employees Annuity Benefit Fund {"The Plan"}	Chicago Police Annuity Benefit Fund {"The Fund"}	Cook County Employees Annuity Benefit Fund {CEABF}
Boston Retirement Board	New York City Fire Dept Article 1B Pension Fund	New York City Police Pension Fund Article 2
Philadelphia Municipal Pension Plan	Dallas Police and Fire Pension System	Pennsylvania Municipal Retirement System
Milwaukee City Employees Retirement System {The System}		

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

Rank	State	Funding ratio 2013 (%)	Funding ratio 2012 (%)	Funding ratio 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:

$$Y = XA + E \quad \text{(C1)}$$

and

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

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 $a = vec(A)$ is a (4×1) vector.

Thus, the likelihood function of Equation (C2) is

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

where

$$(y - (I_m \otimes X)a)'(\Sigma_e^{-1} \otimes I_T)(y - (I_m \otimes X)a) =$$

$$(\Sigma_e^{-0.5} \otimes I_T)(y - (I_m \otimes X)a)'(\Sigma_e^{-0.5} \otimes I_T)(y - (I_m \otimes X)a) =$$

$$[(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a)]'(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a)]$$

and also

$$(\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a)$$

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

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

Therefore we have

$$(y - (I_m \otimes X)a)'(\Sigma_e^{-1} \otimes I_T)(y - (I_m \otimes X)a) =$$

$$((\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols})'((\Sigma_e^{-0.5} \otimes I_T)y - (\Sigma_e^{-0.5} \otimes X)a_{ols}) \quad \text{(C4)}$$

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

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:

$$\int(a\,,\varSigma_e)\infty|\varSigma_e\otimes I_T|^{-0.5}\exp\{-0.5(a_{ols}-a)'(\varSigma_e^{-1}\otimes X'X)\;(a_{ols}-a)$$

$$-0.5(\varSigma_e^{-0.5}\otimes I_T)y-(\varSigma_e^{-0.5}\otimes X)a_{ols})'[(\varSigma_e^{-0.5}\otimes I_T)y-(\varSigma_e^{-0.5}\otimes X)a_{ols})]\}$$

$$=|\varSigma_e|^{-0.5k}\exp\{-0.5(a_{ols}-a)'(\varSigma_e^{-1}\otimes X'X)(a_{ols}-a)\}$$

$$\times|\varSigma_e|^{-0.5(T-k)}\exp\{-0.5tr[(\varSigma_e^{-0.5}\otimes I_T)y$$

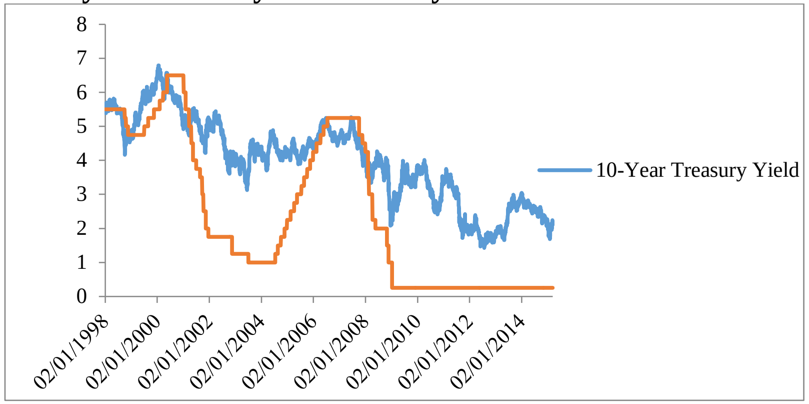
$$-(\varSigma_e^{-0.5}\otimes X)a_{ols})'[(\varSigma_e^{-0.5}\otimes I_T)y-(\varSigma_e^{-0.5}\otimes X)a_{ols})]\}$$

$$\infty\mathbb{N}(a|a_{ols},\varSigma_e,X,y)\times\mathbb{W}(\varSigma_e^{-1}|y,X,a_{ols},T-k-m-1) \qquad \text{(C6)}$$

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

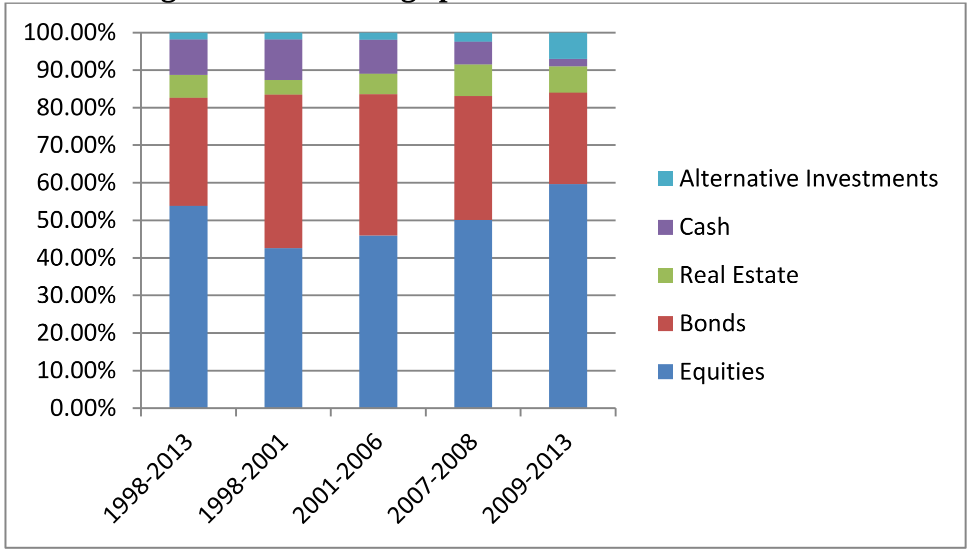
The conditional posterior for a will be normal and the conditional posterior of $\varSigma_e^{-1}$ will be Wishart.

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



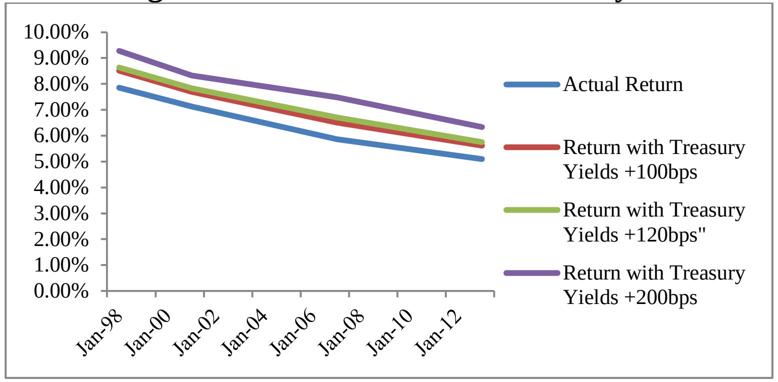
Notes: The figure shows nominal yields from 1998 to 2013 on 10-year Treasury bonds for the U.S. and the federal funds target rate set by the Federal Open Market Committee.

Figure 2. The average pension funds asset allocation



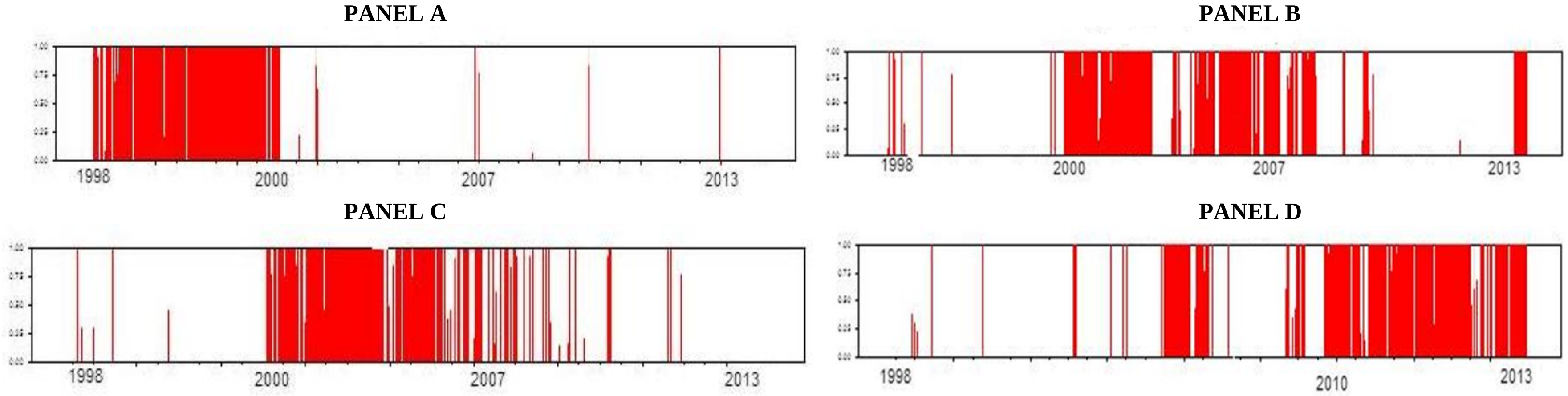
Note: The figure presents the allocation for the following time-periods: from 1998–2013 (overall sample period), from 1998–2000 (period 1), from 2001–2006 (period 2), from 2007–2008 (period 3), and from 2009–2013 (period 4). The sample contains 151 pension funds from 50 states.

Figure 3. BVAR counterfactual analysis



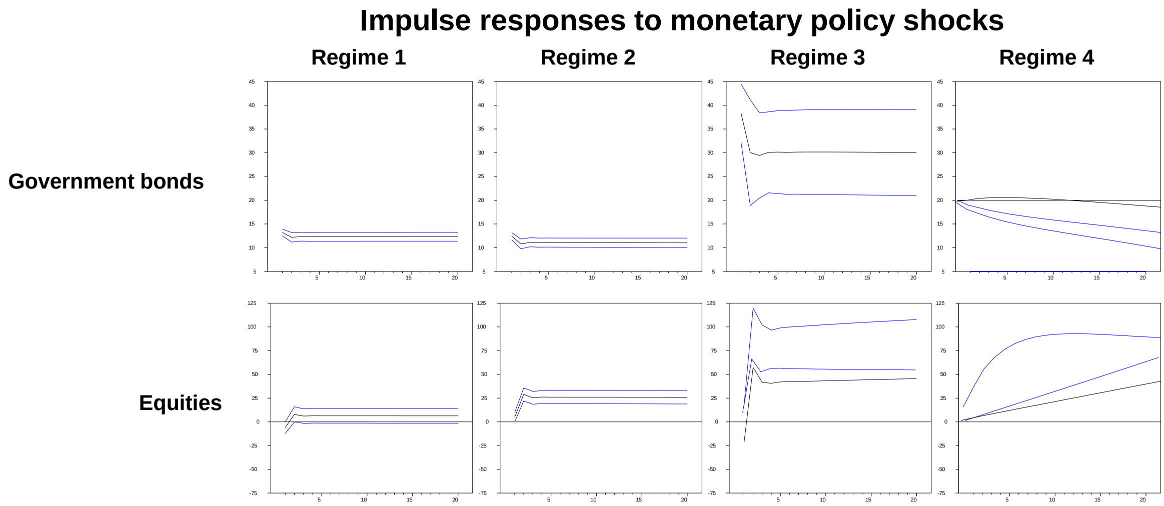
Note: The figure shows the persistence of monetary policy shocks on pension funds risk-taking behavior. The actual return refers to the achieved investment return in pension assets from 1998 to 2013. Three scenarios are simulated, where the Treasury yield is higher by 100 basis points, 120 basis points,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

Figure 4. MS-SVAR switching regimes



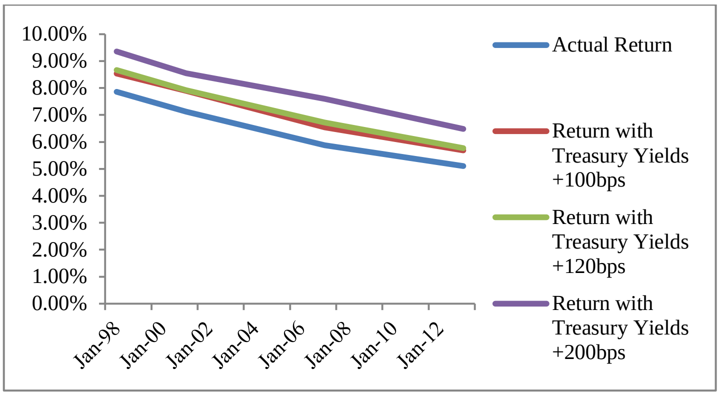
Note: The figure illustrates the four Markov regimes, estimated using the MS-SVAR model. Panel A shows regime 1 (1998–2000) where interest rates increased. Panel B displays regime 2 (2001–2006) where interest rates declined. Panel C exhibits regime 3 (2007–2008) where interest rates increased moderately. 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. The figure summarizes responses by pension funds regarding the allocation of government bonds and equities following changes in the monetary policy framework. 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, due to the increase in interest rates. On the contrary, the response of equities is initially positive, but later it becomes negative. Finally, during Regime 4 (i.e. interest rates at historically low levels) the response of government bonds is overly negative, while equities respond positively.

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. 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	0.0786	0.0419	0.0575	0.0800	0.0900
1 Year Inv. Return	0.0558	0.1204	– 0.3070	0.0884	0.3165
3 Years Inv. Return	0.0522	0.0627	– 0.1370	0.0521	0.1790
5 Years Inv. Return	0.0536	0.0361	– 0.0354	0.0420	0.2566
10 Years Inv. Return	0.0687	0.0254	– 0.0147	0.0720	0.1390
Funding Gap Ratio	0.8244	0.1962	0.1910	0.8250	19.7395

Panel B: Pension asset allocation, overall sample period

	Mean	Standard deviation	Minimum	Median	Maximum
Equities	0.5387	0.1227	0.0000	0.5610	0.7540
Domestic Equities	0.3621	0.1242	0.0000	0.3850	0.7157
International Equities	0.1644	0.0639	0.0000	0.1681	0.3604
Bonds	0.2732	0.0970	0.0000	0.2630	1.0000
US Govern. Bonds	0.2598	0.1131	0.0000	0.2500	1.0000
International Bonds	0.0244	0.0241	0.0000	0.0030	0.0990
Real Estate	0.0607	0.0415	0.0000	0.0596	0.2840
Cash	0.0244	0.0299	0.0000	0.0017	0.2250
Alternative Invest.	0.0184	0.0756	0.0000	0.0440	0.5662
Pension Asset Beta	0.5743	0.1938	0.3839	0.5042	0.6988

Table 2. 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	Standard deviation	Minimum	Median	Maximum
Equities	0.4252	0.0988	0.000	0.4276	0.5781
Domestic Equities	0.3473	0.0659	0.000	0.3401	0.9422
International Equities	0.0779	0.0382	0.000	0.0428	0.1935
Bonds	0.4094	0.0960	0.000	0.3607	1.0000
US Govern. Bonds	0.3910	0.0634	0.000	0.4687	1.0000
International Bonds	0.0184	0.0116	0.000	0.0121	0.0380
Real Estate	0.0385	0.0361	0.000	0.0390	0.0874
Cash	0.1086	0.0573	0.000	0.1006	0.3069
Alternative Invest.	0.0183	0.0204	0.000	0.0162	0.0877
Pension Asset Beta	0.4846	0.1053	0.000	0.4493	0.5625

Panel B: Pension asset allocation, period 2: 2001–2006

	Mean	Standard deviation	Minimum	Median	Maximum
Equities	0.4598	0.1173	0.000	0.4922	0.6002
Domestic Equities	0.3806	0.0821	0.000	0.3886	0.9166
International Equities	0.0792	0.0505	0.000	0.0940	0.2580
Bonds	0.3758	0.1008	0.000	0.3979	0.9800
US Govern. Bonds	0.3623	0.0647	0.000	0.4635	1.0000
International Bonds	0.0135	0.0155	0.000	0.0160	0.0500
Real Estate	0.0550	0.0574	0.000	0.0862	0.1208
Cash	0.0903	0.0531	0.000	0.1011	0.2464
Alternative Invest.	0.0191	0.0226	0.000	0.0164	0.1093
Pension Asset Beta	0.5096	0.1207	0.000	0.4683	0.6030

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

	Mean	Standard deviation	Minimum	Median	Maximum
Equities	0.5002	0.1198	0.000	0.5276	0.7240
Domestic Equities	0.3207	0.1036	0.000	0.4045	0.7982
International Equities	0.1795	0.0702	0.000	0.2071	0.4083
Bonds	0.3306	0.0998	0.000	0.3060	1.0000
US Govern. Bonds	0.3250	0.0531	0.000	0.3005	1.0000
International Bonds	0.0056	0.0107	0.000	0.0024	0.0400
Real Estate	0.0845	0.0603	0.000	0.0629	0.3356
Cash	0.0602	0.0221	0.000	0.0684	0.1477
Alternative Invest.	0.0245	0.1004	0.000	0.0166	0.1214
Pension Asset Beta	0.5433	0.1482	0.000	0.4883	0.6671

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

	Mean	Standard deviation	Minimum	Median	Maximum
Equities	0.5964	0.1388	0.000	0.5876	0.7650
Domestic Equities	0.3602	0.1352	0.000	0.3899	0.7379
International Equities	0.2362	0.0893	0.000	0.2301	0.4287
Bonds	0.2441	0.0925	0.000	0.2175	1.0000
US Govern. Bonds	0.2298	0.1069	0.000	0.1833	1.0000
International Bonds	0.0253	0.0263	0.000	0.0049	0.1102
Real Estate	0.0692	0.0485	0.000	0.0654	0.2950
Cash	0.0201	0.0391	0.000	0.0017	0.2250
Alternative Invest.	0.0635	0.0640	0.000	0.0612	0.5984
Pension Asset Beta	0.6881	0.1539	0.000	0.4902	0.7409

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

Table 4. 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 equities		
	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 > x^2	0.48	–	0.52	0.59	–	0.53
Pension funds	151	151	151	151	151	151
R–squared: Period 1	0.01	0.01	0.01	0.02	0.02	0.02
R–squared: Period 2	0.02	0.02	0.02	0.02	0.02	0.02
R–squared: Period 3	0.02	0.02	0.02	0.01	0.01	0.01
R–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 equities		
	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 > x^2	0.49	–	0.51	0.53	–	0.51
Pension funds	151	151	151	151	151	151
R–squared: Period 1	0.01	0.01	0.01	0.02	0.02	0.02
R–squared: Period 2	0.02	0.02	0.02	0.02	0.02	0.02
R–squared: Period 3	0.02	0.02	0.02	0.01	0.01	0.01
R–squared: Period 4	0.02	0.02	0.02	0.02	0.02	0.01

Table 5. 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 6. 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 7. Shocks, regimes and effects – MS-SVAR

Regime/Shock	Effect on G. B yields	Effect on asset allocation 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 positive (≥)	Positive (>)	Slightly negative (≤)	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 the Quantitative Easing program.

Table 8. 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 9. 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 10. 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