In Search of Habitat

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Abstract

We perform portfolio level analysis to trace the preferred habitat investment behavior in the government bond market. With a preferred habitat, investors would have an inelastic demand to bonds at given horizons. This is confirmed by the empirical evidence that the aggregate portfolios of insurance firms exhibit restrained elasticities to interest rate changes. We further investigate two forms of habitat—a liability habitat driven by the need to immunize the interest rate risk of operating liabilities, and a horizon habitat due to the preference for holding securities with riskfree returns for the investment horizon. Consistent with the two effects, we find that insurers' portfolio interest rate risk is strongly related to that of the operating liabilities, and that the size of liability and risk aversion dampen insurers' portfolio response to term structure changes.

1 Introduction

Preferred habitat is among the earliest hypotheses on the term structure of interest rates. Its origin can be traced to Modigliani and Sutch (1966) in an analysis of the early-1960 Treasury endeavor dubbed "operation twist". Under this hypothesis, the rigidity of investor demand for bonds at specific maturities affects the shape of the interest rate curve, hence there is room for the government to fine-tune the term structure by changing the net supply of bonds across maturities. Much interest in the preferred habitat theory surged around the recent Federal Reserve's "quantitative easing" (QE) programs. Recent studies apply preferred habitat to understand the impact of demand and supply shifts in the bond market. The focus of these studies is on the macro-economic level implications of preferred habitat.[1] To date, there is no empirical evidence on investors' inelastic demand for bonds at given horizons, the microeconomic foundation of the preferred habitat hypothesis.

This study examines the habitat behavior using information on government bond portfolios of insurance firms, an important group of players in the fixed-income market. Casual observations have often identified insurers (and pension funds) as "habitat investors," who have inflexible demand for government bonds of certain horizons (e.g., Vayanos and Vila, 2009). More importantly, there are substantial variations in terms of insurers' operations, potentially driving differential horizons of insurers' investment portfolios. For example, life insurers may prefer bonds of long-term maturities while property and casualty (PC) insurers

[1] For example, using the UK pension reform of 2004 and the US Treasury's buyback program of 2000-2002, Greenwood and Vayanos (2010a) demonstrate that shifts to clientele demand and bond supply affect term structure movements. Hamilton and Wu (2012) show that when short-term interest rate is at the zero lower bound, monetary policy can affect the term structure by changing the maturity of government bonds held by investors. Krishnamurthy and Vissing-Jorgensen (2011, 2012) find that the Federal Reserve's purchase of long-term Treasuries and other long-term bonds in the 2008-2011 period have significant impact on the term structure as well as on yields of mortgage-backed securities. Swanson (2011) uses high frequency data to reevaluate the effectiveness of "Operation Twist," the event that motivated the original analysis of Modigliani and Sutch (1966). Li and Wei (2012) incorporate the supply factors into an arbitrage-free term structure model and estimate the combined impact of the Federal Reserve quantitative easing programs on the ten-year Treasury yield to be around 100 basis points. D'Amico and King (2013) present evidence on the preferred habitat theory by showing a significant "local supply" effect in the Treasury term structure during the Federal Reserve's 2009's quantitative easing program. Finally, it is important to note that there are critiques to the preferred habitat interpretation of monetary policy effectiveness; see, for example, Cochrane (2011).

may prefer short-term bonds as PC insurers' liabilities are typically short term. The impacts of firm operational characteristics on the portfolio choices of different insurers sheds direct light on the micro-foundation of preferred habitat.

We focus on two potential drivers for the habitat preference of sophisticated institutional investors. The first is the need to hedge interest rate risk of their liabilities. Institutional investors such as life insurers and pensions have long-maturity liabilities. The desire to immunizing the interest rate risk of their liabilities results in demand for long-term bonds that is inelastic to the fluctuation of the interest rates. The second cause, as highlighted by recent theoretical studies such as Campbell and Viceira (2001), Watcher (2003), Liu (2007), and Detemple and Rindisbacher (2010), is the preference by risk-averse investors to hold securities that offer risk-free returns at their investment horizon, coming from firms' performance evaluation cycle or executive tenure, which is independent of the liability horizon. This form of habitat is derived with individual investors in mind. Yet, recent studies suggest that industrial firms and financial institutions behave in a risk-averse manner in their investment decisions (e.g., Smith and Stulz, 1985; Froot and Stein, 1998; Froot, 2007). We are thus interested in whether institutional investors have a similar incentive to hedge horizon-specific interest rate risk.

To provide a conceptual framework for empirical analysis, we introduce a simple model of dynamic portfolio choice that nests these two sources of habitat. In the model, habitat shows up as two optimal portfolio weight components exogenous to market interest rate conditions. The first component immunizes the interest rate risk of liabilities while the second component hedges the interest rate risk with respect to the investment horizon. The model provides testable implications that link investors' portfolio interest rate risk exposure to their liability and risk aversion characteristics, They are referred to as the liability habitat and horizon habitat, respectively. The demand to hedge interest rate risks from both habitats drives the testable implications. First, insurers' interest rate risk exposure is positively correlated with the interest rate risk of the liabilities. Second, the size of insurers' liabilities (relative to portfolio value) and risk aversion driven by horizon habitat dampen the portfolio response to term structure factors.

We quantify the habitat behavior based on insurers' bond durations, which embodies the idea of the model that habitat is due to interest rate risk hedging. From a hedging perspective, maturity does not perfectly characterize the "location" of habitat because interest rates are correlated across maturities and the interest rate risk at any given maturity can be hedged using bonds of other maturities. In this context, we identify habitat as the stability of portfolio exposure to systematic risk factors in the term structure.[2] [3] Specifically, we look at the inelasticity of three generalized portfolio duration measures. These duration measures are developed under the Nelson-Siegel term structure model (e.g., Diebold and Li 2006; Diebold, Ji, and Li 2006), and intuitively capture insurers' portfolio exposure to the major term structure factors, i.e., the level, slope, and curvature. For robustness, we alternatively test the habitat behavior by examining the inelasticity of portfolio weights at various maturities.

We begin by documenting several tale-telling signs of habitat detected in the aggregate government bond holdings of property and casualty (PC) insurers and life insurers. First, PC insurers' aggregate portfolio loads heavily on short-maturity bonds while life insurers' aggregate portfolio spreads the weights across maturities. This is consistent with the liability characteristics of these two types of insurers, i.e., the short-term nature of property and casualty policies and the long-term nature of life insurance policies. Second, the aggregate portfolio durations fluctuate in a tight range around the means. For example, the interest rate level duration (equivalent to the Macaulay duration) of PC (life) insurers has a standard deviation of 0.49 (0.93) years around a mean of 5.56 (10.04) years. The slope and curvature durations are in even more confined ranges. Third, the aggregate portfolios' durations, as well as the portfolio weights at various maturities, exhibit limited elasticities in response to

[2]This echoes an insight developed by Vayanos and Vila (2009). They show that due to the factor structure of interest rates, the effect on interest rates by the habitat demand at a given maturity is no longer local; it ripples through the entire yield curve.

[3]Exogenous supply shocks could also affect investors' bond holdings at specific maturities. For example, from September 2001 to January 2006, the U.S. Treasury did not issue any new 30-year bonds. Thus the change in 30-year bond holdings may not be a pure response to the risk-return trade-off in the market.

large swings of the term structure during the 12-year period.

We then examine individual insurers' portfolios. Interestingly, the relative stable portfolio characteristics found at the aggregate level are the result of largely heterogeneous portfolio choices by individual insurers. For example, across PC insurers, the interest rate level duration varies with a 10th-90th percentile range of 2.37 to 7.68 years. The corresponding range is 2.86 to 11.38 years for life insurers. Further, individual insurers' portfolio characteristics are quite stable over time despite the large cross-sectional dispersion. Thus, individual insurers have highly heterogenous but also persistent preferences for interest rate risk.

We subsequently investigate the effects of liability and horizon habitats in the cross section of insurers. First, we find that insurers whose operating liabilities have longer maturities allocate higher portfolio weights on long-term bonds, and that insurers' portfolio durations are positively related to the interest rate risk exposure of operating liabilities. This is evidence for the liability habitat. Second, we find that more risk-averse insurers have lower portfolio durations and allocate higher portfolio weights toward short-term bonds.[4] This is consistent with a horizon habitat effect for investors with short investment horizons.

A critical implication of the habitat effect is that the presence of habitat dampens investors' portfolio response to term structure changes. We present evidence on this feature by analyzing individual insurers' portfolio elasticity in response to term structure changes. Specifically, we obtain the response coefficients by regressing an insurer's portfolio durations and portfolio weights onto the interest rate factors (after controlling for a passive effect of interest rate change in portfolio durations). Based on a bootstrap analysis, we find that insurers' portfolio elasticities exhibit abnormally low cross-sectional dispersion, suggesting somewhat collective efforts by insurers to dampen their portfolio responses to interest rate changes.

We further look at the relation of portfolio elasticities with insurers' liability and risk

[4]We construct four proxies of risk aversion for insurance firms following the corporate risk management literature, which suggests that the financing constraint or convex external financing cost is an important determinant of firms' risk aversion in investment and hedging decisions. Our financing constraint/risk aversion proxies are based on an insurer's affiliation with parent firms, dividend paying status, firm age, and capital adequacy.

aversion characteristics. We find that the absolute elasticities of portfolio durations to interest rate factors tend to be negatively related to insurers' liability ratio, i.e., the amount of operating liability relative to the portfolio value. The dampening effect of insurers' liability on portfolio responses is significant for life insurers but insignificant for PC firms. The liabilities of PC firms are typically short term and liabilities account for smaller proportion of insurer assets than the liabilities of life insurers. Interest rate hedging hence plays a less important role for PC firms. Specifically, across life insurers, a 1% increase in the liability ratio would result in a 0.1% reduction in the absolute level duration elasticity to the level interest rate factor. This finding is a clear support to the impact of liability habitat. Moreover, the tests also reveal that the absolute portfolio duration elasticities to the level factor tends to be negatively related to insurers' risk aversion.

Finally, we separately examine the persistence of insurers' corporate bond holding over the Federal Reserve's quantitative easing (QE) program as a further test on the habitat investment behavior. Starting in late 2008, the Fed purchased long-term financial assets, including long-term government bonds and mortgage backed securities, from banks, insurance companies and other financial institutions. The direct consequence of the QE program is it lowers the yields of long-term bonds. Therefore, if insurers' demand to corporate bonds is not confined by any habitat, insurers may profit from the low yields of long term bonds by selling long-term bonds and shifting their investments to other securities (such as stocks or corporate bonds). We find that durations of life insurers' corporate bond portfolios during QE period (2009 through 2011) preserve the same ranking as the pre-QE period while durations of corporate bonds of PC firms are less persistent. The liability ratios of life insurers continue to dampen their portfolio responses to the adjustments in interest rate factors. The finding renders additional support to the presence of habitat investments.

Overall, our findings suggest the existence of inelastic demand on government bond portfolios by insurers, and thus offer microeconomic-level support to a key assumption of the preferred habitat theory. Further, insurers' habitat behavior can be linked to their operating and financial characteristics, especially the characteristics of operating liabilities.[5] Our analysis on the demand side of government bonds sets it apart from, but complements, a growing macroeconomic and macrofinance literature that examines the supply side issues in this market, such as Greenwood and Vayanos (2010b), Krishnamurthy and Vissing-Jorgensen (2011), Hamilton and Wu (2012), and Li and Wei (2012).

Our study also contributes to a stream of research that examines strategies and performance of investors' government bond portfolios; e.g., Ferson, Henry, and Kisgen (2006) and Huang and Wang (2010). This literature is young relative to the vast number of studies on investors' equity portfolios. A challenge researchers face is that that interest rate factors affect portfolio return and risk in a nonlinear way, making it difficult to apply the linear factor approach developed in the equity portfolio literature. The Nelson-Siegel term structure framework, and the corresponding portfolio duration measures employed by this study, offer an intuitive and convenient way to quantify portfolio interest rate risk, and thus hold promise in analyzing many issues unique to fixed income investments.

The remaining of the paper is organized as follows. Section 2 introduces a simple dynamic portfolio choice model that nests the liability habitat and horizon habitat. Section 3 discusses the data and methodology. Section 4 provides the empirical results. Section 5 concludes.

2 A Tale of Two Habitats: The Model

To provide a conceptual framework for empirical analysis, we first introduce a dynamic portfolio model to analyze insurers' habitat behavior. The model nests two forms of preferred habitat. The horizon habitat arises because of the preference of a risk-averse investor for securities offering safe returns at her investment horizon. The liability habitat is due to the

[5] Our evidence for the investment horizon channel is somewhat mixed. However, such evidence is not a verdict on the horizon habitat that is cast under the setting of individuals' investment and consumption decisions. As noted in the beginning of Section 2, institutions' liabilities are related to individuals' investment and consumption decisions. Thus at the macroeconomic level, institutions' liability habitat may be potentially reconciled with individuals' horizon habitat.

need to hedge interest rate risk of her liability.[6]

2.1 Horizon Habitat

We start with a model of only the horizon habitat. Consider an investor with initial wealth W_0 at time 0, whose objective is to maximize expected utility from wealth at time H. There is no intermediate consumption. At any given time t, there are always M bonds available for trading. These bonds do not have default risk, and are priced according to a general term structure of stochastic interest rates. Let R_{mt} be the one-period gross return from time t-1 to t for bond m. For convenience let the first bond be the one-period riskfree bond. We assume that the remaining M-1 bonds are non-redundant in the sense that the M-1 by M-1 covariance matrix for the return R_{mt} (m=2,..., M) has a full rank. After one bond matures it can be replaced by any other non-redundant bond. Market completeness is not required.

Let ω_{mt} be the portfolio weight on bond m at time t. The investor has a power utility function with a relative risk aversion coefficient of γ. Thus, the optimization problem at time 0 is:

$$\text{Max} E_0(\frac{W_H^{1-\gamma}}{1-\gamma}) \tag{1}$$

subject to the budget constraint: $W_{t+1} = W_t R_{pt+1}$, where $R_{pt+1} = \sum_{m=1}^{M} \omega_{mt} R_{mt+1}$ is the portfolio return.

A discussion on the utility function is in order here. In the traditional corporate finance view, a firm's financial objective is to maximize the net present value of its investments and the risk of the investment is irrelevant beyond its effect on the discount rate. However, the more recent literature suggests that firms and financial institutions do behave in a risk-averse way when making investment and risk management decisions. Several reasons for corporate

[6] From a macroeconomic point of view, the liability habitat of institutional investors may be related to the horizon habitat of individuals, because institutional investors' liabilities could be traced to individuals' consumption and investment decisions. For example, the maturities of pension liabilities are related to employees' retirement horizons, and the maturities of life insurance claims are determined by policyholders' life expectancies. Nonetheless, institutional investors play an active role of risk sharing, liquidity provision, and maturity transformation. Their habitat demand for bonds needs not be the same as the habitat demand directly from individuals. Therefore we treat these two forms of habitat separately.

risk aversion have been identified, such as the risk aversion of corporate managers or key stakeholders (Stulz 1984), the effect of corporate tax (Smith and Stulz 1985), the cost of financial distress (Smith and Stulz 1985), and convex external financing cost (Froot, Scharfstein and Stein, 1993; Froot and Stein, 1998; Froot, 2007). Finally, the capital adequacy regulations on financial institutions serve as an exogenous enforcement on their risk averse behavior when making investment and risk management decisions. Our assumption of an risk-averse institutional investor follows this literature. The specific assumption of a power utility function is in line with the existing literature on preferred habitat.

We derive an "closed-form" solution for the optimal portfolio weights based on a "change of numéraire" procedure in the spirit of Detemple and Rindisbacher (2010) and log-linearization following Campbell and Viceira (1999) and Campbell, Chan, and Viceira (2003). Appendix A.1 shows that the optimal portfolio weight has the following form:

$$\omega_{\mathbf{t}} = \frac{1}{\gamma}\mathbf{\Omega}^{-1}(E_t\mathbf{r_{t+1}} - r_{ft+1}\iota + \frac{1}{2}\mathbf{V}) + \frac{\gamma-1}{\gamma}\mathbf{\Omega}^{-1}\mathrm{Cov}(\mathbf{r_{t+1}}, r_{ht+1}) + \frac{1-\gamma}{\gamma}\mathbf{\Omega}^{-1}\mathrm{Cov}(\mathbf{r_{t+1}}, x_{t+1}) \tag{2}$$

where $\omega_{\mathbf{t}}$ is a vector of optimal weights for the M-1 risky bonds. $E_t(\mathbf{r_{t+1}})$, $\mathbf{V}$ and $\mathbf{\Omega}$ are the expected return vector, variance vector, and covariance matrix of their log returns. r_{ft+1} is the log risk free rate. ι is a unit vector. r_{ht+1} is the return of a zero-coupon bond maturing at time H. We do not require this bond to be among the M bonds available for trading, as long as its prices are observed. $r_{p\tau}$ is the log portfolio return and $x_{t+1} = \sum_{\tau=t+2}^{H}(r_{p\tau} - r_{h\tau})$ summarizes the future portfolio "risk premium"—log portfolio return in excess of the log return to the maturity-H bond.

The optimal portfolio weight in Equation (2) consists of three terms. The first term is a static mean-variance component. The second term hedges against the interest rate risk of the maturity-H bond, and the third term hedges against future changes in "risk premium." The horizon habitat is represented by the second term, which is a demand for securities that can hedge the interest rate risk at maturity H, i.e., the investment horizon.

To gain further intuition, consider the relation of the three terms with the risk aversion coefficient γ. Under log utility, i.e., $\gamma = 1$, only the first component remains and the two hedging components disappears. This results in the well-known "myopic portfolio". On the other hand, as $\gamma \to \infty$, the myopic component converges to zero, and $(\gamma-1)/\gamma$ and $(1-\gamma)/\gamma$ in the two hedging components converge to 1 and -1 respectively. On appearance both hedging components do not disappear. However, in the risk premium hedging component x_{t+1} represents future portfolio risk premiums. If the entire portfolio converges to a single position in the H-maturity bond, x_{t+1} converges to zero, and so does the entire risk premium hedging component.[7] Therefore, as risk aversion increases, the importance of the interest rate hedging component increases, and the portfolio weight on the H-maturity bond reaches 1 in the limit.

2.2 Liability Habitat

We now introduce the liability habitat. Suppose the investor faces a debt of \$L due at time K, with $1 < K \leq H$. Without loss of generality, we assume the existence of a buy-and-hold portfolio at time 0 based on the M bonds available, which delivers a riskless payoff of \$1 at time K and zero at any other time. Let ω^L_{mt} denote the time-t weight of this portfolio on bond m. If out of the M zero-coupon bonds there is one with maturity K, then a feasible portfolio is to put a 100% weight on this bond and zero weights on other bonds. But it is suffice to assume the existence of a portfolio mimicking the payoff of this bond.

The investor maximizes the same expected utility function as in (1), with the modified budget constraint:

$$\text{Max} E_0(\frac{W_H^{1-\gamma}}{1-\gamma}) \tag{3}$$

subject to the following budget constraint: for t $\neq$ K, $W_{t+1} = W_t R_{pt+1}$; and for t=k, $W_{t+1} = (W_t - L)R_{pt+1}$.

Appendix A.2 shows that the optimal portfolio for this problem has two components. The first component completely immunizes the fluctuation of the present value of the liability, and the second component is the optimal portfolio without liability, i.e., the solution to (1). More

[7] The convergence of x_{t+1} to zero can be verified by solving $\omega_{\mathbf{t}}$ and x_t backward, starting from time H-1. With infinite risk aversion, the utility loss due to any risk exposure dominates the utility gain from any expected return. Thus the optimal investment has to make the terminal wealth W_H riskless.

specifically, Let B_t be the time-t value of the buy-and-hold portfolio that delivers a safe \$1 payoff at time K. At time 0, start holding this portfolio at the amount of LB_0. This position is held without rebalancing until time K, at which point the portfolio is liquidated to completely pay off the liability. Thus at any time before K, the value of this position is LB_t. This is the immunization component of the portfolio. The second component allocates the remaining value of the time-t wealth, $W_t - LB_t$, to bond m according to the weight ω_{mt}, which is the optimal weight in the problem of (1). Let $\alpha_t = LB_t/W_t$. Combining the two components together, the weight for bond m in the entire portfolio is $\omega^*_{mt} = \alpha_t \omega^L_{mt} + (1-\alpha_t)\omega_{mt}$. After time K, $\alpha_t = 0$ and the portfolio weight goes back to the optimal weight for the problem (1), i.e., $\omega^*_{mt} = \omega_{mt}$. Appendix A.2 provides further discussion on three extensions of the basic model here.

The liability habitat is represented by the portfolio component $\alpha_t \omega^L_{mt}$. The purpose of this component is to completely neutralize the interest rate risk of the liability. This form of hedging is known as complete immunization or cash flow matching in the asset-liability management practice. In the static optimization setting, it is unclear whether complete immunization or some less stringent form of hedging is better. Complete immunization is nonetheless optimal in the dynamic portfolio problem considered here. Intuitively, this is because immunization is costless measured by the marginal utility of the investor, which is in turn due to that in the optimal portfolio without liability, the investor is already indifferent between holding the maturity-K bond (or the mimicking portfolio ω^L_t) and holding any other bonds.

2.3 Model Implications

Combining the form of optimal portfolio with liability and the log-linear solution (2) for the portfolio weights without liability, we have the following log-linear representation of the optimal portfolio:

$$\omega^*_{\mathbf{t}} = \alpha_t \omega^{\mathbf{L}}_{\mathbf{t}} + (1-\alpha_t)\frac{\gamma-1}{\gamma}\omega^{\mathbf{H}}_{\mathbf{t}} + (1-\alpha_t)(\frac{1}{\gamma}\omega^{\mathbf{O1}}_{\mathbf{t}} + \frac{1-\gamma}{\gamma}\omega^{\mathbf{O2}}_{\mathbf{t}}) \tag{4}$$

where $\omega_{\mathbf{t}}^{\mathbf{L}}$ is the vector of ω_{mt}^{L}. $\omega_{\mathbf{t}}^{\mathbf{H}} = \mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, r_{ht+1})$. $\omega_{\mathbf{t}}^{\mathbf{O1}} = \mathbf{\Omega}^{-1}(E_t\mathbf{r_{t+1}} - r_{ft+1}\iota + \frac{1}{2}\mathbf{V})$ and $\omega_{\mathbf{t}}^{\mathbf{O2}} = \mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, x_{t+1})$. The first component in the above expression is the liability habitat, the second one is the horizon habitat, and the third one is the "opportunistic" component, i.e., the myopic component plus the risk premium hedging component. An immediate issue to note is that the liability habitat component $\omega_{\mathbf{t}}^{\mathbf{L}}$ matches the risk of liability but does not necessarily have the same maturity as the liability. The same can be said about the horizon habitat component $\omega_{\mathbf{t}}^{\mathbf{H}}$. Thus, these two forms of habitat are better characterized by their effect on the interest rate risk of the portfolio, rather than by their effect on the maturities of portfolio holdings.

An important feature of the fixed income market is that a few systematic term structure factors affect the term structure of interest rates—for example, the well-known level, slope, and curvature factors (Litterman and Scheinkman, 1991). A portfolio's interest rate risk can be summarized by the sensitivities of portfolio value to these systematic factors. Consider an example where the interest rate level risk is measured by the Macaulay duration. The duration of the optimal portfolio described by (4) have the following duration expression:

$$D_t = \alpha_t D_t^L + (1-\alpha)\frac{\gamma - 1}{\gamma} D_t^H + (1-\alpha)\left(\frac{1}{\gamma} D_t^{O1} + \frac{1-\gamma}{\gamma} D_t^{O2}\right) \tag{5}$$

where D_t^L, D_t^H, D_t^{O1} and D_t^{O2} are the durations of the sub-portfolios with weights $\omega_{\mathbf{t}}^{\mathbf{L}}$, $\omega_{\mathbf{t}}^{\mathbf{H}}$, $\omega_{\mathbf{t}}^{\mathbf{O1}}$, and $\omega_{\mathbf{t}}^{\mathbf{O2}}$ respectively. We can generalize this duration expression for other interest rate factors and draw three testable implications.

The *first implication*, the liability duration effect, is that a portfolio's interest rate risk exposure is positively related to the interest rate risk of the liability. That is, $\partial D_t / \partial D_t^L > 0$.

Eq (5) further suggests that the horizon habitat effect on portfolio duration depends on the risk aversion γ as well as D_t^H. In the context of the Macaulay duration, D_t^H can be directly interpreted as the investment horizon. However, the investment horizon is not directly observed.[8] Our empirical strategy is to identify proxies for insurers' risk aversion, and detect the presence of the horizon habitat via the relation between observed portfolio duration and risk aversion. From Eq. (5), we have:

$$\frac{\partial D_t}{\partial \gamma} = \frac{1}{\gamma^2}(1-\alpha_t)(D_t^H - D_t^O) \tag{6}$$

where $D_t^O = D_t^{O1} + D_t^{O2}$, the "opportunistic duration."

The *second implication* of the model, the horizon habitat effect, follows Eq (6). If the investment horizon duration D_t^H is longer than the opportunistic duration D_t^O, then portfolio duration D_t increases with risk aversion; however if D_t^H is shorter than D_t^O, D_t decreases with risk aversion.

Finally, the interest rate factors may serve as state variables that summarize the time varying investment opportunities an investor faces, thus affecting portfolio choices.[9] The role of interest rate factors as state variables takes effect on the portfolio weights via the components $\omega_{\mathbf{t}}^{\mathbf{O1}}$ and $\omega_{\mathbf{t}}^{\mathbf{O2}}$, and accordingly, on the portfolio duration D_t via the components D_t^{O1} and D_t^{O2}. On the other hand, both the liability and investment horizon components ($\omega_{\mathbf{t}}^{\mathbf{L}}$ and $\omega_{\mathbf{t}}^{\mathbf{H}}$, and accordingly, D_t^L and D_t^H) are relatively exogenous to the interest rate changes. That is, $\partial D_t^L/\partial f_t = 0$ and $\partial D_t^H/\partial f_t = 0$. Then, based on Eq. (5) we can further characterize the elasticity of portfolio duration with respect to a factor f_t as:

$$\frac{\partial D_t}{\partial f_t} = (1-\alpha_t)\left(\frac{1}{\gamma}\frac{\partial D_t^O}{\partial f_t} - \frac{\partial D_t^{O2}}{\partial f_t}\right) \tag{7}$$

It can be seen that the direction at which α_t and γ affect the portfolio elasticity, i.e., $\partial D_t/\partial f_t$, depends on the signs of $\partial D_t^O/\partial f_t$ and $\partial D_t^{O2}/\partial f_t$. Without taking a view on what should be their correct signs, we can look at the effect of α_t and γ on the absolute portfolio elasticity,

[8] The concept of investment horizon of a financial institution is somewhat complicated. Financial institutions such as insurers are expected to survive a long time, therefore they potentially have long investment horizons. However, corporate executives and investment managers at these institutions may have much shorter expected tenures and their performance may be evaluated at even shorter periods, potentially resulting in short investment horizons. See Gaspar, Massa, and Matos (2005) for causes of alternative investment horizons.

[9] A caveat is that yield curve factors may not fully characterize time varying investment opportunities. For example, there might exist unspanned stochastic volatility (e.g., Collin-Dufresne and Goldstein 2002). Cochrane and Piazzesi (2005) identify a forward-rate factor that predicts bond returns but is weakly related to conventional yield curve factors.

i.e., $|\partial D_t/\partial f_t|$. From Eq. (7), α_t negatively affects $|\partial D_t/\partial f_t|$. We can further infer a negative relation between γ and $|\partial D_t/\partial f_t|$. To begin with, note that $|\frac{1}{\gamma}\frac{\partial D_t^O}{\partial f_t}|$ decreases with γ. Next, note that D_t^{O2} is the duration of $\omega_{\mathbf{t}}^{\mathbf{O2}} = \mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, x_{t+1})$, which, as explained earlier, converges to zero as γ increases. Thus $|\partial D_t^{O2}/\partial f_t|$ decreases with γ.

This gives rise to the *third implication*, the impact of habitat effect on portfolio elasticity: the size of liability (α_t) and risk aversion (γ) reduce the absolute portfolio elasticity to interest rate factors.

3 Data and Methodology

3.1 Data

We use two datasets from the National Association of Insurance Commissioners (NAIC). The first contains securities holdings and trades by insurance firms, known the "Schedule D" data. The Schedule D data have detailed information on bond holding by each insurer at the end of each year and record of each bond transaction occurred during that year. In addition, the Schedule D data provide basic bond information such as issuer type, maturity, coupon, yield, and price.[10] The second is insurers' demographic information and financial statements, known as INFOPRO data. Insurers are required by state insurance regulators to disclose their portfolio holdings and trading information (including stocks, bonds and other securities) and detailed data of their insurance operations. NAIC compiles the filings and distributes them.

To construct the sample of government bonds, we start with all straight U.S. treasury bonds and agency bonds reported in the Schedule D data. These government bonds are classified into two categories in the data: 1) issuer obligations, which are direct obligations of the government and government agencies that are backed by the full faith and credit of the United States government, and 2) mortgage-backed/asset-backed securities, which are pass-through certificates and other "securitized loans issued by the United States government

[10]In fact, the Schedule D data is the source of the Mergent FISD bond transaction data.

that are exempt pursuant to the determination of the Valuation of Securities Task Force. We focus on securities with only interest rate risk. Thus we only keep the issuer obligation bonds and exclude the mortgage/asset-based securities. We exclude bonds with special characteristics such as bonds with credit enhancements, foreign currency bonds, puttable, callable, or exchangeable bonds. We also require the bonds to have non-missing coupon rates and positive face values. A few bonds with apparently incorrect CUSIPs are also excluded.

Further, we require the sample to have information from the INFOPRO database. We exclude pure reinsurance firms (by requiring firms to have non-zero direct underwriting premiums) and a few small insurers with total assets below $5 million. The INFOPRO dataset has financial information on insurers as well as insurance groups and holding companies that many insurers belong to. We exclude the group-level and holding company-level firms.

The sample period is from 1999 to 2011. To ensure sufficient data for analysis on individual insurers, we require an insurer to have portfolio data for at least 5 years during which it holds at least 5 government bonds. There are 1,378 unique PC insurers and 520 unique life insurers in our final sample.

Insurers hold other types of securities and instruments that are subject to interest rate risk, such as corporate bonds, municipal bonds, mortgage backed securities, and interest rate derivatives. Quite possibly, insurers include these alternative instruments when managing their interest rate risk exposure. We focus on government bonds in the main part of this study for the following two reasons. First, our primary objective is to examine the inelastic demand for government bonds per se. The inelasticity of government bond demand is an important issue in recent monetary policy debate. The Federal Reserve's second Large Asset Purchase Program solely focuses on buying the long-term government bonds. The absence of inelasticity in long-term government bond demand would call into question the rationale of this endeavor. Evidence from existing studies also supports a focus on government bonds. For example, Greenwood and Vayanos (2010b) and Krishnamurthy and Vissing-Jorgesen (2011) report that supply shocks to Treasury securities do affect the Treasury yield curve more than affecting interest rates of other fixed income securities. Second, other assets such as corporate bonds and mortgage-backed securities carry additional risk other than the interest rate risk (e.g., default risk and prepayment risk). To quantify such additional risks and determine their correlations with the interest rates will necessarily introduce further complications. Nonetheless, in the internet appendix of this paper, we perform analysis on insurers' entire fixed-income portfolios and look at insurers' interest rate derivative use.

3.2 The Nelson-Siegel Term Structure Model and Portfolio Durations

There are several popular approaches to characterize the term structure and interest rate factors, from the principal component method, to the affine latent-factor models, and to the cross-sectional yield curve fitting using parameterized functions. This paper adopts the third approach. We use a parsimonious polynomial-exponential function known as the Nelson and Siegel (1987) model to fit the cross-section of zero-coupon yields. Specifically, we follow the Diebold and Li (2006) version of the model:

$$y_t(n) = \beta_{0t} + \beta_{1t}\frac{1-e^{-n\lambda_t}}{n\lambda_t} + \beta_{2t}\left(\frac{1-e^{-n\lambda_t}}{n\lambda_t} - e^{-n\lambda_t}\right) \tag{8}$$

where $y_t(n)$ is the continuously-compounded time-t zero-coupon yield for maturity n. β_{0t}, β_{1t}, β_{2t}, and λ_t are time-varying parameters.

One reason for our choice of the Nelson-Siegel model is that it provides an intuitive way to characterize the three most important features of the yield curve, i.e., the level, slope, and curvature. Diebold and Li (2006) show that the three parameters β_{0t}, β_{1t}, and β_{2t} have very high levels of correlation (0.97, -0.99, and 0.99 respectively) with the conventional measures of level (the 10-year yield), slope (the difference between the 10-year and 3-month yields), and curvature (twice the 2-year yield minus the sum of the 3-month and 10-year yields). They also report that these three estimated parameters are relatively independent of each other. We refer to β_{0t}, β_{1t}, and β_{2t} as the level, slope, and curvature factors, with the understanding that β_{1t} is the negative of the conventional slope factor. In addition, the parameter λ_t determines the location of the curvature top.

There are alternatives to the Nelson-Siegel model. For example, Piazzesi and Schneider (2010) explore the affine term structure approach to characterize interest rate risk exposure of U.S. household portfolios. Relative to the affine models, the Nelson-Siegel model in its general form does not impose no-arbitrage restrictions (e.g., Diebold, Piazzesi, and Rudebusch 2005). However, it is computationally convenient, and thus is particularly useful for applications where the number of bonds involved is very large and the no-arbitrage condition is not mission-critical. This is the second reason for our choice of the Nelson-Siegel model.

When estimating the model, we follow Diebold and Li (2006) to fix the value of λ_t to a constant of 0.0609, which exogenously specifies the curvature top at 30 months. This enables us to estimate β_{0t}, β_{1t}, and β_{2t} using OLS. The zero-coupon yields $y_t(n)$ used in estimation are at the 30 consecutive annual maturities from 1 to 30 years. We run the regression in each sample year using the year-end yields. The yield data are obtained from Gürkaynak, Sack, and Wright (GSW, 2007).[11]

The first four plots in Figure 1 are the yield curves from the GSW data at four selected years in our sample period, representative of different market conditions: shortly after the LTCM crisis (1998), after the burst of the internet bubble (2002), at the height of the real estate bubble (2006), and in the midst of the financial crisis (2009). The yield curve is pretty flat in 1998 but becomes steep with low short rates in 2002 in response to a loose monetary policy. The curve is flat in 2006 but becomes steep again in 2009 after the QE1. The fitted Nelson-Siegel yield curves are also plotted. Overall, the fitted curve stays quite close to the actual curve.[12]

The last three plots in Figure 1 are the time series of estimated level, slope, and curvature factors. Consistent with the term structure variations observed in Figure 1, the three factors

[11] The GSW data are available at http://www.federalreserve.gov/pubs/feds/2006/200628/feds200628.xls. Their zero-coupon yield estimates are smoothed across a large cross-section of bond prices. Although unsmoothed yields are more desirable, to our knowledge the GSW data represent the only public data for long-maturity zero-coupon yields. Cochrane and Piazzesi (2008) compare the GSW data with the Fama-Bliss (1987) data (with yields for maturities up to 5 years). They find that the difference is quite small.

[12] There are slightly more deviations at the long-end of maturity than at the short-end. This may be due to the "second hump" in the yield curve, a feature that entails the Svensson (1994) extension of the Nelson-Siegel model. However, judged by the plots, the magnitude of the second hump during our sample period appears to be not material for the purpose of this study.

have large swings during the sample period. Note that β_1 is the negative of slope—more specifically, the loadings of short-maturity yields on this factor are negatively while the loadings of long-maturity yields converge to zero—thus a low (negative) value of β_1 indicates a upward slope.

The Nelson-Siegel model framework offers close-form expressions for the interest rate risk (i.e, partial derivatives) of bond price with respect to the three term structure factors β_{0t}, β_{1t}, and β_{2t}. Based on bond price sensitivities we further derive portfolio sensitivities to term structure factors, in a way similar to the conventional notion of bond duration. The generalized portfolio duration measures under the Nelson-Siegel model are derived in Willner (1996) and Diebold, Ji, and Li (2006). We refer to them as the the level, slope, and curvature durations, and collectively as the NS durations. To derive these durations, note that the price of a bond can be expressed as:

$$P_t = \sum_{i=1}^{N} C_i e^{-n_i y_t(n_i)} \tag{9}$$

where N is a bond's number of payments remaining (relative to time t). C_i is the i-th remaining payment (coupon and principal combined) of the bond, relative to time t. n_i is the time to the due date of the payment. Let the weight of the present value of the i-th payment in the bond price be $v_{it} = C_i e^{-n_i y_t(n_i)}/P_t$. The three NS durations for the bond are:

$$\mathrm{DL}_t = -\frac{\partial P_t/P_t}{\partial \beta_{0t}} = \sum_{i=1}^{N} v_{it} n_i \tag{10}$$

$$\mathrm{DS}_t = -\frac{\partial P_t/P_t}{\partial \beta_{1t}} = \sum_{i=1}^{N} v_{it}(1 - e^{-n_i\lambda_t})/\lambda_t \tag{11}$$

$$\mathrm{DC}_t = -\frac{\partial P_t/P_t}{\partial \beta_{2t}} = \sum_{i=1}^{N} v_{it}\left[(1 - e^{-n_i\lambda_t})/\lambda_t - n_i e^{-n_i\lambda_t}\right] \tag{12}$$

By construction, the level duration DL is equivalent to the Macaulay duration.

The NS durations for a bond portfolio are the weighted averages of the NS durations of bonds in the portfolio:

$$\mathrm{DURL}_t = \sum_{j=1}^{M} w_{j,t}\mathrm{DL}_{j,t},\ \ \mathrm{DURS}_t = \sum_{j=1}^{M} w_{j,t}\mathrm{DS}_{j,t},\ \ \mathrm{DURC}_t = \sum_{j=1}^{M} w_{j,t}\mathrm{DC}_{j,t}$$

where $w_{j,t}$ is the portfolio weight on bond j.

As noted earlier, habitat is the lack of elasticities by portfolio durations with respect to the interest rate factors. Empirically, we quantify such elasticities using the coefficients obtained from regressing portfolio durations onto the corresponding interest rate factors.

3.3 Portfolio Weights Across Maturity Bins

Following the more traditional view of habitat, we also look at the elasticities of portfolio weights. We calculate the cash flow weights of a bond portfolio in the following way. First, we separate each cash flow of a bond (i.e., coupons and principals) according to its own maturity. We create 10 maturity bins across the 30-year spectrum, with each bin covering three years of maturity. For example, bin #1 spans zero to three year maturities, bin #2 includes maturities greater than three years and up to six years (inclusive), and so forth. The 10th bin covers the maturities from 27 years to 30 years (inclusive). A very small number of bonds in our sample have cash flows maturing beyond 30 years. We create an additional bin #11 to include such cash flows. We group all the cash flows of an insurer's government bond portfolio into the maturity bins. The portfolio weight of cash flows in a maturity bin is the total amount of cash flows in the bin divided to the total amount of cash flows of the portfolio. The elasticities of portfolio weights are the coefficients obtained from regressing portfolio weights onto the interest rate factors.

Our portfolio weight calculation is based on the amount of cash flows instead of the present value of cash flows. Such a cash flow weight measure has the advantage of being exogenous to term structure changes. By comparison, portfolio weights based on the present values of cash flows are endogenous to the term structure because the interest rates are used to discount the cash flows. As a consequence, the present-value based portfolio weights may change with interest rates even when there is no trading, thus confounding the inference on portfolio elasticity to interest rate changes.

3.4 Liability and Risk Aversion Characteristics

3.4.1 Insurers' Liability Characteristics

Insurance firms have little financial debt and their liabilities mainly come from their operations. In general, the interest rate risk exposure of insurers' operating liabilities comes from the timing difference between the cash inflows from the collection of insurance premiums, and the cash outflows due to claim payments. Between the two major types of insurance policies, i.e., PC and life policies, there are differences in the interest rate risk exposure of their operating liabilities.

The PC insurance policies are effectively short-term contracts and tend to have relatively short-term interest rate risk exposure. Although the customer relationship can be long-term, the PC policies are typically renewed annually. At the time of policy renewal, insurance premiums are adjusted, presumably to reflect the prevailing market interest rate conditions and thus limiting the policies' exposure to long-term interest rate risk. Payments are only made to losses incurred during the year of policy coverage. If all payments are made immediately after the losses, the present value of a PC policy's cash flows is not exposed to the interest rate risk beyond one year. However, for various reasons some payments occur years after the initial loss claims are made, thus introducing long-term interest rate risk to PC insurance operations. Payments made to losses incurred more than a year ago are termed "claim tails". PC insurers are required to report annually their claim tails for prior 10 years to the state insurance regulators, which is part of the INFOPRO data known as "Schedule P".

Life insurance policies are long-term contracts and have substantial long-term interest rate risk exposure. A "whole-life" policy collects premiums periodically (e.g., annually) and pays a fixed amount of benefit at the death of the policyholders. Often a "whole-life" policy also has a cash value that can be withdrawn when the policyholder reaches a certain age (e.g., 65 years). A "term-life" policy collects periodical premiums and pays a fixed amount of death benefit within a pre-specified term of coverage (e.g., 10 years) but does not pay any additional cash value. For both whole-life and term-life insurance, once a policy is in effect, the periodic premiums are not adjusted for market interest rate conditions. Therefore the present values of both the cash inflows (premiums) and the cash outflows (claim payments) fluctuate with the interest rates and the overall interest rate risk of a policy is determined by that of the net cash flows.[13] In addition, life insurers often offer healthcare insurance that covers medical expenses. Healthcare policies are typically renewed annually, in a way similar to PC policies. However due to the long-term nature of some medical treatments and the complexity of payment processing, healthcare insurance can have relatively long claim tails; that is, payments may occur several years after the initial claims. Thus the interest rate risk exposure of healthcare policies tend to be higher than that of PC policies but substantially lower than conventional life policies.

We construct measures of the interest rate risk of PC insurers' operating liabilities based on their historical claim tails reported in the "Schedule P" data. Using this data we project the claim payments of an insurer for the next 10 years following a "chain ladder" method that is popular in the insurance industry. Based on projected payments we further estimate an insurer's claim durations with respect to the three interest rate factors, level, slope, and curvature, in a way similar to the portfolio durations described in Section 3.2. These three claims durations are referred to as CDURL, CDURS, and CDURC, respectively. Further details of this procedure are provided in the internet appendix of this paper.

Life insurers however are not required to report their claim tails; further, the interest rate risk mainly arises from the long-term nature of their life policies. Therefore we quantify the interest rate risk exposure of life insurers' operating liabilities based on the idea that life insurers engage in non-life business (such as healthcare insurance) that has much lower interest rate risk than life insurance. To be specific, our proxy for life insurer's interest rate risk exposure, PctLife, is the the percentage of premiums collected from life policies in total premiums collected, based on the INFOPRO data.

[13] In addition, there are two types of non-conventional life policies—universal life and variable life. With universal life policies, policyholders can increase or decrease the death benefits and associated premiums based on their needs. Such an option increases the cash flow uncertainty of the policies. Under variable life insurance, the cash value of a policy depends on the cumulative return to the investment portfolio associated with the policy and therefore does not subject insurers to interest rate risk. According to the 2011 American Council of Life Insurer's Fact Book, about 61 percent of life insurance policies sold in the United States in 2010 are whole (or cash value) life insurance policies as opposed to term life insurance policies.

Finally, our model discussed in Section 2.3 involves α, the ratio of liability to the portfolio value. The empirical measure of α is the liability ratio (LR), the ratio of claims-related operating liability to the value of investment portfolio. The operating liability is obtained from insurers' financial statements titled "Liabilities, Surplus, and Other Funds" (part of the INFOPRO data). For PC insurers, it is the sum of 1) Losses, 2) Reinsurance payable on paid losses and loss adjustment expenses, and 3) Loss adjustment expenses. For life insurers, it is the sum of 1) Aggregate reserve for life contracts, 2) Aggregate reserve for accident and healthcare contracts, 3) Liabilities for deposit-type contracts, and 4) Contract claims. The denominator of LR is the data item "Invested Assets" from the same financial statements.

3.4.2 Risk Aversion Proxies

The second and third implications of our model involve an insurer's risk aversion. So far there is no established way of measuring the risk preference of financial institutions. Our risk aversion proxies are motivated by the economic theory of corporate risk management. A prominent reason for firms to engage in financial hedging and risk management is the existence of convex external financing cost or financing constraints (Froot, Scharfstein, and Stein, 1993). Firms with higher external financing costs will also act more averse to investment portfolio risk. Based on this financing constraint effect, we construct the following four risk aversion proxies using the INFOPRO data.[14]

- INDEP: a dummy variable for an insurer not affiliated with any parent group or holding company. Parent groups and holding companies can reduce external financing costs of subsidiaries and provide additional risk sharing across subsidiaries. Independent firms do not enjoy such benefit (e.g., Lamont 1997, Stein 1997, Kahn and Winton 2004, and

[14]We have considered two additional proxies for financing constraints but do not include them in the analysis reported in the paper—firm size and and the mutual status of an insurer. The reasons are the following. First, in our data, firm size has a highly positive correlation of 0.44 with the liability ratio LR. Therefore it is unclear whether the effect of firm size on insurers' portfolio choices is due to financing constraint or liability. Second, although insurers with mutual ownership are sometimes perceived as having more difficulty accessing the capital market than do stock insurers, a recent study by Berry-Stolzle, Nini and Wende (2012) shows that mutual insurers have access to capital markets by issuing surplus notes. Therefore, the mutual status may not be a good proxy for financing constraint.

Zanjani 2010).

- NODIV: a dummy variable for an insurer not paying any dividends to either policyholders or stockholders. Dividend paying status is a popular measure of financing constraint (e.g., Almeida and Campello 2007, and Li and Zhang 2010).

- YOUNG: the negative of the logarithm of firm age. Younger firms typically are more financially constrained (e.g., Fee, Hardlock, and Pierce 2009, and Rauh 2006).

- LOWCAP: the negative of the logarithm of an insurer's capital adequacy ratio, which is the total adjusted capital relative to the authorized control capital level. Ellul, Jotikasthira, and Lundblad (2011) find that insurers with lower capital adequacy ratios are more likely to engage in asset fire sales. Shim (2010) shows that undercapitalized insurers are under pressure to increase capital to avoid regulatory costs.

3.5 Summary Statistics

Table 1 reports the summary statistics on the characteristics of sample insurers, in four representative years (1998, 2002, 2006, 2009, and 2011) and for the time series averages.

The number of PC insurers in the sample increases from 888 in 1998 to 968 in 2006, then drops to 740 in 2011. The number of life insurers exhibits a similar time trend: it changes from 541 in 1998 to 551 in 2002, then drops to 388 in 2011. PC insurers' average total assets is $1,071.54 million; by contrast, life insurers are bigger, with an average total asset of $7,718.28 million. On average, invested assets account for 85% of PC insurers' total assets, with the majority investments in stocks and bonds (74% of total assets), and prominently in bonds (63% of the total assets). Notably, 22% of total assets are government bond holdings. By comparison, life insurers have more invested assets (90% of total assets) and invest more in bonds (74% of total assets), although the fraction of government bond holdings is slightly lower (17% of total assets).

PC insurers' average liability ratio (LR) is 38.26%. The average length of the interest rate level duration of claims liabilities, CDURL, is 2.28 years, while the average slope and curvature durations, CDURS and CDURC, are 1.10 and 0.56, respectively. 29.19% are not affiliated with a parent group or holding company. 79.69% of PC insurers do not pay dividends. The average age of PC insurers is 31 years, and their average capital adequacy ratio is 12.56%. Relative to PC insurers, life insurers have a higher average liability ratio (LR), at 65.92%. Life insurers have a bit more than half of underwriting business in the life insurance sector (64.78%), with the rest in health and annuity business. 33.19% are independent firms. About 72% life insurers do not pay dividends. Their average age is 50 years, with an average capital adequacy ratio of 20.40%.

The table further reports the standard deviations of insurer characteristics calculated along the firm dimension and time dimension. The cross-firm standard deviation of a firm characteristic is calculated in a given year across all PC or life insurers, and then averaged over years. The within-firm standard deviations of a firm characteristic is calculated for a given firm using all its time series data, and then averaged across firms. The table shows that the cross-firm standard deviations of insurer characteristics are much larger than those within-firm standard deviations. For example, the cross-firm dispersion of the liability ratio LR is 32.37% for PC insurers and 29.20% for life insurers, about three times the within-firm variation of 8.62% and 9.88% respectively. This suggests that firm characteristics vary widely across insurers, and that the time fluctuation of firm characteristics for a typically insurer is relatively low. In a panel-data framework, these firm characteristics represent stable firm-fixed effects with large cross-firm variations.

4 Empirical Results

4.1 Insurer Aggregate Portfolios

There is a macro-economic level interest in knowing how insurers' collective bond investments respond to market interest rate conditions. Therefore, we start by examining the aggregate portfolios of PC insurers and life insurers respectively. We pool all the government bond holdings of PC insurers into one aggregate portfolio, and those of life insurers into another aggregate portfolio. For each aggregate portfolio we compute the three durations as well as the cash flow weights in 11 maturity bins following Section 3.2 and Section 3.3.

Panel A of Table 2 reports the attributes of the aggregate portfolio durations and aggregate cash flow weights. The time series average of the interest level duration for PC insurers' aggregate portfolio is 5.98 years, while that for life insurers' is 10.91 years. The duration difference between PC and life insurers is consistent with the different interest rate risk of their operating liabilities—PC policies are short-term contracts subject to annual renewal and the claims are paid off fairly quickly, while life policies are long-term contracts and the claims are distributed through a long period of time. In addition, life insurers' aggregate portfolio has a higher slope duration (1.31 vs. 1.24) and a higher curvature duration (1.20 vs. 1.02) than those of PC insurers'. The portfolio weights at various maturities exhibit a consistent pattern. PC insurers put a heavy 58% cash flow weight in the two maturity bins at the short end, and the weights drop off quickly as the maturity extends. By contrast, life insurers spread out the weights across maturities. They have 41% cash flow weights in maturities beyond 15 years. There are two interesting spikes in the weight distribution, one around the 10-year (bin #4) and another around the 30-year (bin #10), coinciding with the most frequent maturities of long-term Treasury bond issues.

A further noted pattern is the low time-series standard deviations of aggregate portfolio durations. The standard deviation of the level duration is 0.50 year for PC insurers and 0.99 year for life insurers, suggesting that insurers manage to keep the interest rate level risk exposure in a tight range around a target (5.98 and 10.91 years). The standard deviations of the slope and curvature durations are even smaller: they are around 2% of the mean for the slope duration and around 5% of the mean for the curvature duration, for both types of insurers. The fluctuations of the portfolio weights are also pretty narrow-ranged at maturities where there is critical mass of cash flows. An exception is the large weight variation in bin #10, which includes the 30-year maturity. A closer inspection of the data shows a large reduction of the 30-year Treasury bonds around the period when the Treasury stopped issuing new 30-year bonds (from August 2001 to January 2006). Such portfolio weight fluctuations are likely the result of supply shocks instead of response to interest rate conditions.

Figure 2 shows how the aggregate portfolio durations respond to the changes in the corresponding interest rate factors over the sample years. The level duration of life insurers' aggregate portfolio tends to increase when the interest rate level decreases. For PC insurers' aggregate portfolio, there is a similar pattern toward the end of the sample period (2007-2009) but not so during the rest of the sample years. The slope durations and curvature durations for both types of insurers stay rather flat relative to the fluctuations of the interest rate factors.

Panel B of Table 2 further reports the elasticities of aggregate portfolio durations to the interest rate factors. The elasticities are estimated as the coefficients from regressing the aggregate portfolio durations onto the respective interest rate factors. Life insurers' aggregate portfolio duration has a significantly negative response coefficient to the level factor, consistent with the visual pattern from Figure 2. PC insurers' aggregate portfolio duration has a negative response coefficient to the slope factor, which is statistically significant at the 10% confidence level. This suggests that the aggregate PC insurer increases the slope risk exposure when the yield curve becomes steeper (i.e., when β_{1t} becomes more negative). However, compared with the level elasticity, the slope elasticity appears to have a small economic magnitude. All other duration response coefficients are insignificant.

We perform similar analysis on the elasticities of the aggregate portfolios' cash flow weights. Figure 3 plots the aggregate portfolio weights in the four representative years: 1998, 2002, 2006, and 2011. As noted earlier, the yield curves are relatively flat in 1998 and 2006 and steep in 2002 and 2011. PC insurers' aggregate portfolio weights do not change much across the four sample years, especially for the first two maturity bins where 60% of the weights are concentrated. Life insurers' aggregate portfolio weights have more variations. However there does not appear to be common patterns between the pair of years with similar yield curves, i.e., between 1998 and 2006, or between 2002 and 2011.

Figure 4 further plots the elasticities (i.e., regression coefficients) of portfolio weights. For

PC insurers, there are three significant coefficients, all at maturities above 12 years where the weights are quite low, thus having small economic impact on the aggregate portfolio. Life insurers' aggregate portfolio significantly reduces the weights in the middle (9-15 year range) and increases the weights in both the short end (0-6 year range) and the long end (24-27 year range) in response to a rising interest rate level. This is a somewhat intriguing way to reduce the level duration. Life insurers' aggregate portfolio weights at the 10th bin (i.e., around the 30-year maturity) have significantly negative elasticities to the slope and curvature factors. However we may not be able to read too much into this because as mentioned earlier, the change in the 30-year bond holdings might be confounded by the lack of new Treasury issues during the 2001-2006 period.

We have performed additional analysis to verify the robustness of the results. First, we perform block bootstraps on the interest rate factors to control for their persistence and obtain inference similar to that drawn on Panel B of Table 2 and Figure 4 (where the t-statistics are based on the Newey-West procedure). Second, interest rate changes can induce passive changes in portfolio durations even when portfolio holdings are constant. We control for this passive effect when estimating portfolio elasticities and obtain similar results. The details on this control are discussed in Section 4.6.

The results obtained in this part of the analysis indicate that both the durations and portfolio weights of insurers' aggregate portfolios fluctuate in a narrow range and have limited responses to term structure changes. However, because we do not know what is the "normal" range of portfolio elasticity for investors without habitat, we cannot conclude definitely that the patterns on the aggregate portfolios are driven by habitat. Further, given the relatively short time series data of the aggregate portfolios, it is difficult to develop more powerful statistical tests to pinpoint the habitat. In the subsequent analysis, we take advantage of the cross-sectional data on individual insurers to sharpen the inference.

4.2 Portfolio Differences across Insurers

We start the cross-sectional analysis by computing the three portfolio durations and cash flow weights for individual insurers. Table 3 reports the cross-sectional distribution of these portfolio attributes. The average interest rate level duration is 4.83 years across PC insurers and 6.77 years across life insurers, both lower than the durations of the aggregate portfolios reported in Table 2. The difference between the cross-sectional averages and the aggregate portfolios is driven by the difference between small and large insurers—larger insurers typically have higher portfolio durations, and exert more influence on the time-series statistics than on the cross-sectional statistics. The small-large differences also help reconcile the portfolio weight statistics reported in Table 3 with those reported in Table 2. For example, relative to the aggregate portfolios, the cross-sectional means of both PC and life insurers' portfolio weights concentrate more on the short maturities, notably the first two bins. The median weights for longer maturities become zero despite positive means. These results can be understood in association with the pattern that smaller insurers have more weights on short-term bonds and less weights on long-term bonds.

More importantly, there is a large cross-sectional dispersion of portfolio attributes. The cross-sectional standard deviation of a given portfolio attribute (e.g., level duration) reported in Table 3 is calculated across insurers in each year and then averaged over time. The cross-sectional dispersion is large in contrast to both the cross-sectional mean and the time series standard deviation, which is estimated first for each insurer and then averaged across insurers. For PC (life) insurers, the cross-sectional standard deviation of the level duration is 2.34 (3.68) year. By contrast, the cross-sectional mean of the level is 4.83 (6.77) years and the time series standard deviation is 1.45 (1.83) years. The cross-sectional standard deviations for the slope and curvature durations appear tighter around the means. Yet the corresponding time series standard deviations are even smaller. The portfolio weights exhibit similarly large dispersion. These results suggest large heterogeneity in portfolio choices across insurers and at the same time quite stable portfolio choice over time for a given insurer. If such a pattern is due to habitat, it must be the case that habitat is highly dispersed across insurers and yet highly stable for a given insurer.

Another highlight of the dispersed nature of habitat is the persistence of portfolio attributes. Table 4 reports the results of Fama-MacBeth cross-sectional regressions, where a portfolio attribute in year t is regressed onto the lagged portfolio attribute of year t-k, with k ranging from one to five years. The three portfolio duration measures exhibit strong persistence. The portfolio weights also exhibit significant persistence, albeit slightly weaker relative to that of portfolio durations.

4.3 Effect of Liability

What explains the persistent cross-sectional differences in insurers' portfolio choices? We follow the model implications to investigate how insurers' operating and financial characteristics affect their portfolio decisions. We start with the first implication—a positive relation between liability duration and portfolio duration.

We use a cross-sectional regression approach to quantify the relation between portfolio duration and liability duration, the rationale of which deserves a note. We have insurer-year observations on portfolio durations and liability durations. That is, the data have a panel structure with both a time dimension and a cross-firm dimension. Accordingly, the relation between portfolio duration and liability duration has a time dimension and a cross-firm dimension. In a panel setting, the former is known as the "within effect" and can be estimated by a panel regression where both the dependent variable and explanatory variable are de-meaned at individual insurer level, i.e., by subtracting the respective insurer-specific means from the portfolio duration and liability duration observations; the latter is known as the "between effect" and can be estimated using a cross-sectional regression, where the dependent variable is the time-series average of portfolio duration for an individual insurer and the explanatory variable is the time series average of the liability duration for the insurer (e.g., Greene 2011).

We have performed both types of regressions. As it turns out, we detect a strong "between effect" while the "within effect" tends to be insignificant. Thus, the relation between portfolio duration and liability duration is largely a cross-sectional effect. This outcome is foreshadowed by the data properties revealed in Table 1 and Table 3—both liability durations and portfolio durations (as well as risk aversion proxies used in subsequent analysis) exhibit large dispersion across insurers but relatively small time-series variation for a given insurer. These data patterns are consistent with the notion that insurers' habitat is stable over time while cross-sectionally dispersed. Given this nature of habitat, in all subsequent analysis we only report the results of the cross-sectional "between-effect" regressions.[15]

Table 5 reports the cross-sectional regression results. As noted above, the dependent variable is the time-series average of an insurer's portfolio duration (DURL, DURS, and DURC) and the explanatory variable is the time-series average of the insurer's liability duration for the same interest rate factor. For PC insurers the liability duration proxies are CDURL, CDURS, and CDURC; for life insurers, PctLife serves as the proxy for the liability exposure to all three interest rate factors. The regression result shows that portfolio durations with respect to the interest rate level factor is significantly positively related to the interest rate level risk of operating liabilities—CDURL for PC insurers and PctLife for life insurers. Recall from Table 1 that the cross-sectional standard deviation of CDURL is 1.00 and that of PctLife is 38.60%. Therefore the regression coefficients reported in Table 5 suggest that one standard deviation increase in CDURL results in an increase of 0.30 year to the interest rate level duration of PC insurers' portfolios, and one standard deviation increase in PctLife results in an increase of 1.31 year to the interest rate level duration of life insurers' portfolios. This confirms that hedging the interest rate level risk of operating liabilities is indeed an important objective when insurers make portfolio investment decisions.

Further, for PC insurers, the relation between DURS and CDURS, and that between DURC and CDURC, are positive but statistically insignificant. On the other hand, for life insurers, the relation of both DURS and DURC with PctLife is significantly positive. This contrast can be understood in association with the following difference between the two types of insurers. The operating liabilities of PC insurers concentrate at short maturities and thus

[15]The results of the "within-effect" regressions are not tabulated but are available upon request.

the present values of the liabilities are not severely affected by the slope and curvature risk. However this is not the case for life insurers, who have a significant amount of long-term operating liabilities.

The results plotted in Panel A of Figure 5, we also perform cross-sectional regressions to understand insurers' portfolio choices at the portfolio weight level, where the dependent variable is the time-series average of portfolio weight for an individual insurer in a given maturity bin. The figure shows that PC insurers with higher CDURL, CDURS, and CDURC have significantly lower weights at short maturities (especially the first two bins) and significantly higher weights at long maturities. Life insurers with higher PctLife shift portfolio weights in the 0 to 6 year maturity range to maturity beyond 6 years. Shifting weights from the short maturities to long maturities increases the interest rate level duration of a portfolio. Thus the portfolio weight results are consistent with those on portfolio durations.

Overall, the results suggest that liability has a strong influence on insurers' portfolio interest rate risk decisions.

4.4 Effect of Risk Aversion

We next turn to the horizon habitat effect. Following the second model implication, we infer horizon habitat via the relation between risk aversion and portfolio durations. Recall that their relation depends on the relative magnitude of the horizon duration (i.e., the investment horizon) and the duration of the opportunistic part of the portfolio. A negative relation indicates that insurers' horizon duration is lower than the duration of their opportunistic portfolio components, and a positive relation suggests the opposite.

We continue to use the cross-sectional regressions for this part of analysis. The dependent variable of the regression is the time-series mean of an insurer's portfolio duration (DURL, DURS, and DURC). The explanatory variable is each of the four risk aversion proxies defined earlier—a dummy for non-affiliated insurers (INDEP), a dummy for firms not paying dividends (NODIV), the negative log of firm age (YOUNG), and the negative log of the risk-based capital (LOWCAP). The regression is performed separately for each of the risk aversion proxies. YOUNG and LOWCAP are the time-series averages for a given insurer. INDEP, and NODIV are measured at the end of the sample period for a given insurer. A small number of insurers in our sample change group affiliation status and dividend policy during the sample period. Our results are robust when we exclude these insurers or use their status at the beginning of the sample period.

The results are reported in Table 5. For PC insurers, when INDEP, NODIV, and YOUNG are used to explain the three portfolio durations, the coefficients are all negative; they are statistically significant except in when case (coefficient on YOUNG when DURS is the dependent variable). LOWCAP, however, has insignificantly positive coefficients. For life insurers, all four risk aversion proxies have significantly negative coefficients across all regressions. Thus, with the exception of LOWCAP for PC insurers, there seems to be a pervasively negative relation between risk aversion and portfolio durations, suggesting that the incentive to hedge interest rate risk associated with the investment horizon results in low exposure for all three term structure factors. In the context of the interest rate level duration, this directly suggests that insurers have short investment horizon, perhaps due to executive tenures or corporate performance evaluation cycles.

We perform similar cross-sectional regressions for portfolio weights, by using time-averaged portfolio weight for an insurer at a given maturity bin as the dependent variable. Panel B of Figure 5 reveals that risk aversion reduces insurers' portfolio weights at long maturities and increases weights at short maturities (notably the first two maturity bins), except for the case of LOWCAP for PC insurers. This is consistent with the result of the portfolio duration regressions and suggests a short investment horizon.

As an additional note, although the results reported in Table 5 and Figure 5 are all based on univariate regression, we have performed multivariate regressions where a liability duration measure is paired with a risk aversion proxy as joint explanatory variables. The results are similar and are not tabulated to conserve space.

4.5 Portfolio Elasticity to Interest Rate Factors

Finally, we take a direct look at individual insurers' portfolio elasticities. The elasticities are measured by the coefficients of time-series regressions, where the dependent variable is adjusted portfolio duration (explained below) or portfolio weight and the explanatory variable is an interest rate factor. Based on the estimated elasticities, we further examine the third model implication—liability and risk aversion reduce portfolio elasticities.

By construction, portfolio durations are joint functions of interest rates and bond cash flows. Portfolio durations change with interest rates even when cash flows do not change. When estimating portfolio duration elasticities, we use the adjusted portfolio durations to control for this passive effect. Conceptually, the adjusted portfolio duration is the duration of the portfolio weight component that represents active deviation from an insurer's average portfolio weight. In operation, it is the portfolio duration minus a "target duration" that captures the passive impact of interest rate change on portfolio duration. We estimate the target duration of an insurer by applying the prevailing interest rates in a given year on the time-averaged cash flow weights following Eq. (10) to Eq. (12). To obtain the time-averaged cash flow weights, in each year we group the expected cash flows (coupons and principals) of an insurer's portfolio into semi-annual maturity bins (as opposed to the 3-year bins used in previous analysis).[16] For each insurer, we compute its cash flow weight in each semi-annual maturity bin each year, and then take the time series average for each bin.

In Table 6, we report the cross-sectional statistics of the estimated portfolio elasticities, including the mean, median, 10th and 90th percentiles, and standard deviations. To assess the statistical significance of the distribution of portfolio elasticities, we perform a bootstrap analysis to obtain a distribution under the null hypothesis that insurer portfolios collectively

[16] The predominant coupon frequency for government bonds is semi-annual. A small number of bonds in our sample have weekly, monthly, and quarterly coupons. Thus using semi-annual bins may result in approximation errors. However by our calculation such approximation errors are small.

do not respond to interest rate changes.[17] The bootstrapped p-values reported in the table are computed as the percentages of the bootstrapped statistics that exceed the corresponding sample statistics. A p-value close to 0 indicates an abnormally high sample statistic relative to the bootstrapped statistics, and a p-value close to 1 indicates an abnormally low sample statistic relative to the bootstrapped statistics.

Panel A of Table 6 provides the cross-sectional distribution of the elasticities of insurers' adjusted portfolio durations to the interest rate level factor. The mean and median elasticities are positive for both types of insurers, but are statistically insignificant based on the bootstrapped p-values. Further, they are economically small compared with the dispersion of the elasticities, which is measured by the cross-sectional standard deviation and the 10th-90th percentile range. Therefore, if insurers respond to interest rate level changes, their responses are quite heterogeneous in directions. More importantly, the bootstrapped p-values suggest that the standard deviations of the elasticities are actually abnormally low. The 10th-90th percentile range reveals a similar pattern: the 10th percentile is abnormally high, while the 90th percentile is abnormally low based on the bootstrapped p-values. This indicates that insurers exercise concerted effort to dampen their absolute portfolio elasticities, despite the dispersed directions of their responses.

The same panel also reports the portfolio weight elasticities to the level factor. The bootstrapped p-values suggest that the dispersion of weight elasticities is abnormally low at short-term maturities for PC insurers and extensively so across maturities for life insurers. This again indicates that insurers exhibit muted response to interest rate level changes.

The elasticities of insurers' adjusted portfolio durations to the slope and curvature factors are reported in Panel B and C of Table 6. The mean and median elasticities are insignificantly

[17] The bootstrap procedure follows that of Jiang, Yao, and Yu (2007) except that interest rate factors are bootstrapped from an AR(1) process to account for the persistence. The bootstrap involves the following steps. First, we estimate an AR(1) model for the monthly time series of each interest rate factor (using the monthly GSW data). Second, by randomly re-sampling the estimated residuals we reconstruct the time series of an interest rate factor. By construction, the bootstrapped factor retains its persistence from the actual data but is uncorrelated with insurers' portfolio durations. Third, we estimate the bootstrapped portfolio elasticities for each insurer using its sample portfolio durations and the bootstrapped factors. Fourth, we record the cross-sectional statistics of the bootstrapped elasticities across all insurers. We repeat these steps 2,000 times to obtain the bootstrapped distributions for these cross-sectional statistics.

negative, while the dispersion of elasticities across insurers remain notably muted. The same panel further shows that the portfolio weight elasticities to the slope and curvature factors exhibit abnormally low cross-sectional dispersion.

Having observed muted portfolio elasticities by insurers, we further examine the effects of liability and risk aversion on absolute portfolio elasticities, i.e., the third implication of the model. We continue to use the cross-sectional regression approach, where the dependent variable is the absolute portfolio duration elasticities to interest rate factors of individual insurers with duration elasticities estimated in the analysis for Table 6. We look at the absolute elasticities because of the dispersed portfolio responses revealed by Table 6—we do not wish to impose a joint hypothesis on what should be the right direction of response in our analysis; further, the Nelson-Siegel model, being cross-sectional in nature, does not offer a view on what should be the “right” direction of portfolio response.

Table 7 reports the results of the cross-sectional regressions. We first examine the liability effect by using the time-averaged liability ratio LR for a given insurer as the explanatory variable. For PC insurers, LR negatively affects the absolute elasticities of portfolio durations to all three factors, and significantly in the case of the curvature factor. For life insurers, LR has a significantly negative impact on the absolute duration elasticities to all three factors. Therefore, liability is an important cause of portfolio inelasticity.

We further regress the absolute elasticities of portfolio weights onto the liability ratio LR. The coefficients plotted in Figure 6 show that for both PC and life insurers, the most visible effect of LR is that it reduces absolute portfolio weight elasticities at short maturities. The relation between LR and absolute weight elasticities at long maturities tends to be positive, although the magnitude of the relation is much lower relative to that at short maturities. As a result, the combined effect of LR on the absolute portfolio duration elasticity is negative (Table 7). This highlights the importance of looking at portfolio duration rather than portfolio weight at a specific maturity in order to “locate” the habitat.

Table 7 further shows that the relation of risk aversion with portfolio duration elasticities tends to be negative, consistent with the third model implication. For each type of insurer, there are 12 pairs of relations based on three portfolio duration measures and four risk aversion proxies. For PC insurers, there are 8 counts of negative relations out of the 12 pairs, among which 5 are significantly negative at the 10% level. For life insurers, there are 8 counts of negative relations, with 6 significantly negative. However, across the four risk aversion proxies, their effects are somewhat mixed on PC insurers' duration elasticities to the curvature factor and on life insurers' duration elasticities to the slope factor.

To sum up, there is pervasive evidence that the liability ratio LR decreases portfolio elasticity. In a majority of cases we also observe a negative impact of risk aversion on portfolio elasticity; however the evidence is less clear-cut across risk aversion proxies. Additionally, in untabulated multivariate regression analysis, we have paired the liability ratio LR with one of the risk aversion proxies as joint regressors, and have obtained results similar to those from the univariate regressions reported in Table 7.

4.6 Insurer's Government Bond Investment after Fed's Quantitative Easing

Started in November 2008, the US Federal Reserve initiated an unconventional monetary policy, quantitative easing (QE), to stimulate the economy. The Fed implemented QE by purchased specified amounts of long term financial assets from banks, insurance companies and other financial institutions, thus increasing the monetary base and lowering the yields on these financial assets.[18] In other words, interest rates of long-term bonds are low when QE is used and interest rates are expected to rise in a long run. Consequently, the implementation of the QE program presents a natural experiment to test insurers' habitat investments: if insurers' demand to long-term government bonds is elastic, we would expect they would invest less in long-term bonds while hold more in short-term bonds during the QE period.

[18] The Fed implemented the quantitative easing program in three rounds. In the first round (later known as QE1) started in late November 2008 and up to October 2010, the Fed purchased over USD2 trillion mortgage-backed securities and Treasury securities. The second round (QE2) began in November 2010 that Fed purchases USD 600 billion of Treasury securities by the end of the second quarter 2011. A third round of QE (QE3) was announced in September 2012 that the Fed purchases USD 40 to 85 billion per month. Our sample covers QE1 and QE2 as the sample ends by 2011.

In this way, they could earn an arbitrage profit from the Fed's QE program.

We test insurers' government bond investment behavior during the period after QE was implemented. Specifically, we redo the analysis reported in Table 5 (testing the effect of liability and risk aversion on portfolio durations) and Table 7 (habitat effect on portfolio elasticities) during the QE period (from 2009 to 2011) and report the results in Table 8. It shows that liability and investment horizons still affect portfolio durations in the QE period. The coefficients are comparable to those reported in Table 5. Moreover, the liability ratios of life insurers continue to dampen their portfolio responses to the adjustments in interest rate factors. In short, these findings are inconsistent with the conjecture that insurers may deviate from their long term targets in the QE period to earn an arbitrage profit when interest rates of long term bonds are extremely low. The results render support to habitat investment behavior.

4.7 Extended Analysis

For reasons explained in Section 3.1, we have focused on the interest rate risk of insurers' government bond holdings, leaving out their investments in other fixed-income securities and interest rate derivatives. In the internet appendix to this paper, we perform analysis on insurers' entire fixed-income securities holdings and examine the impact of the use of interest rate derivatives. We find that all the main conclusions based on the government bond portfolios continue to hold for insurers' entire bond portfolios. We also find that insurers use interest rate derivatives and government bond portfolios in a complementary way to manage their overall interest rate risk exposure. Further, insurers using interest rate derivatives exhibit a similar degree of inelasticity in their government bond demand, when compared with insurers not using interest rate derivatives.

5 Conclusions

This study provides empirical evidence on the microeconomic foundation of the preferred habitat hypothesis. Using detailed government bond holdings, we quantify insurers' portfolio interest rate risk exposure and estimate their portfolio elasticities to interest rate factors. We detect habitat-like behavior in insurers' aggregate portfolios and across individual insurers' diverse portfolio choices. There is further evidence that insurers' portfolio interest rate risk and portfolio elasticities to interest rate factors are related to their liability and risk aversion characteristics. Our findings highlight institutional investors' liabilities as an important source of inelastic demand for government bonds.

Appendix A

A.1. Horizon Habitat: "Change of Numéraire" and Log-linearization

Let the one-period log riskfree rate from time t-1 to t be r_{ft}. Let R_{ht} and r_{ht} be the gross return and log return of a zero-coupon bond maturing at time H, for the period from time t-1 to t. This bond pays off a value of \$1 at maturity and its time-t price is B_t^H.

Define $\hat{W}_t = W_t/B_t^H$. Essentially, W_t^* is wealth expressed in the units of the H-maturity bond. This in the same spirit of the "change of numéraire" procedure in Detemple and Rindisbacher (2010). Since $B_H^H = 1$, $W_H = \hat{W}_H$, and the investor's problem in (1) is equivalent to:

$$\text{Max} E_0 (\frac{\hat{W}_H^{1-\gamma}}{1-\gamma}) \tag{13}$$

subject to the budget constraint:

$$\hat{W}_{t+1} = \hat{W}_t R_{pt+1}/R_{ht+1}$$

Recall that $R_{1t+1} = B_{t+1}^H / B_t^H$ is the return to the H-maturity bond. The indirect utility function J_t, combined with the wealth process, can be expressed as:

$$J_t = E_t(J_{t+1}) = \hat{W}_t^{1-\gamma} E_t \frac{\left(\Pi_{\tau=t+1}^H R_{p\tau}/R_{h\tau}\right)^{1-\gamma}}{1-\gamma} \tag{14}$$

The log-linearized approximate solution to (13) follows the approach developed by Campbell and Viceira (1999) and the multivariate version of Campbell, Chan, and Viceira (2003). Let $r_{pt+1} = ln(R_{pt+1})$ denote the log portfolio return. Further, let $x_{t+1} = \sum_{\tau=t+2}^H (r_{p\tau} - r_{h\tau})$. Let σ_p^2, σ_h^2 and σ_x^2 be the variance of r_{pt+1}, r_{ht+1}, and x_{t+1} respectively, which can be time varying but their time subscripts are dropped for notational convenience. The log-linearized indirect utility function of (14) becomes:

$$\begin{aligned} \text{ln} J_t = -\text{ln}(1-\gamma) + (1-\gamma)\text{ln}\hat{W}_t + (1-\gamma)E_t(r_{pt+1} - r_{ht+1} + x_{t+1}) \\ +\frac{1}{2}(1-\gamma)^2(\sigma_p^2 + \sigma_h^2 + \sigma_x^2 + 2\text{Cov}(r_{pt+1}, x_{t+1}) - 2\text{Cov}(r_{pt+1}, r_{ht+1}) - 2\text{Cov}(r_{ht+1}, x_{t+1})) \end{aligned}$$

We then log-linearize the portfolio return:

$$r_{pt+1} = \omega_{\mathbf{t}}'(\mathbf{r_{t+1}} - \iota' r_{ft+1}) + r_{ft+1} + \frac{1}{2}\omega_{\mathbf{t}}'\mathbf{V} - \frac{1}{2}\omega_{\mathbf{t}}'\mathbf{\Omega}\omega_{\mathbf{t}}$$

where $\omega_{\mathbf{t}}$ is a vector (M-1 by 1) of the weights on the remaining M-1 bonds (excluding the first one-period riskfree bond), $\mathbf{r_{t+1}}$ and $\mathbf{V}$ are vectors (M-1 by 1) of the log returns r_{mt+1} and the variances of log returns to the remaining M-1 bonds. $\mathbf{\Omega}$ is the covariance matrix (M-1 by M-1) of their log returns. Further, we have,

$$\begin{aligned} \sigma_p^2 &= \omega_{\mathbf{t}}'\mathbf{\Omega_t}\omega_{\mathbf{t}} \\ \text{Cov}(r_{pt+1}, x_{t+1}) &= \omega_{\mathbf{t}}'\text{Cov}(\mathbf{r_{t+1}}, x_{t+1}) \\ \text{Cov}(r_{pt+1}, r_{ht+1}) &= \omega_{\mathbf{t}}'\text{Cov}(\mathbf{r_{t+1}}, r_{ht+1}) \end{aligned}$$

Taking the derivative of J_t with respect to the portfolio weights and using the above expressions, we can obtain the following first order condition:

$$E_t(\mathbf{r_{t+1}}) - r_{ft+1} + \frac{1}{2}\mathbf{V} - \omega_{\mathbf{t}}{}'\Omega + \frac{1}{2}(1-\gamma)(2\omega_{\mathbf{t}}{}'\mathbf{\Omega} - 2\text{Cov}(\mathbf{r_{t+1}}, r_{ht+1}) + 2\text{Cov}(\mathbf{z_{t+1}}, x_{t+1})) = 0$$

which leads to the log-linearized optimal portfolio weight solution:

$$\omega_{\mathbf{t}} = \frac{1}{\gamma}\mathbf{\Omega}^{-1}(E_t\mathbf{r_{t+1}} - r_{ft+1}\iota + \frac{1}{2}\mathbf{V}) + \frac{\gamma-1}{\gamma}\mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, r_{ht+1}) + \frac{1-\gamma}{\gamma}\mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, x_{t+1})$$

It is interesting to compare this expression with the log-linear solution under the traditional dynamic programming approach without the "change of numéraire":

$$\omega_{\mathbf{t}} = \frac{1}{\gamma}\mathbf{\Omega}^{-1}(E_t\mathbf{r_{t+1}} - r_{ft+1} + \frac{1}{2}\mathbf{V}) + \frac{1-\gamma}{\gamma}\mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, \sum_{\tau=t+2}^{H} r_{p\tau})$$

The equivalence of the two solutions can be established by noting that $\sum_{\tau=t+2}^{H} r_{p\tau} = x_{t+1} + \sum_{\tau=t+2}^{H} r_{h\tau} = x_{t+1} - ln(B_t) - r_{ht+1}$. However, in the traditional dynamic programming solution, the intuition for the interest rate hedging motivation and the convergence property of the two hedging components (explained in the main text), are not straightforward.

The horizon habitat effect has been derived previously in various portfolio problems. Watcher (2003) provides a proof that in complete market and with infinite risk aversion, the optimal portfolio is a zero-coupon bond maturing at the investment horizon. Liu (2007) obtains a similar result for incomplete market under quadratic term structure. Based on log-linearization, Campbell and Viceira (2001) show that with infinite horizon and intermediate consumptions, the optimal portfolio converges to a console bond as risk aversion increases. Lioui and Poncet (2001) and Detemple and Rindisbacher (2010), using the martingale approach, show that the horizon habitat originates from the interest rate hedging component of the optimal portfolio. We show that the "change of numéraire" procedure can be applied in the dynamic programming approach to deliver the same intuition.

A.2. Optimal Portfolio Weights with Liability

For t≤K, the portfolio return is $R_{pt} = \alpha_{t-1}R_{Kt} + (1-\alpha_{t-1})Z_{pt}$. Here, $R_{Kt} = \sum_{m=1}^{M} \omega_{mt-1}^{L} R_{mt}$ is the gross return from time t-1 to t of the portfolio delivering a safe \$1 at time K. $Z_{pt} = \sum_{m=1}^{M} \omega_{mt-1} R_{mt}$ is the return to the second component of the portfolio, i.e., the optimal portfolio without liability. The optimal portfolio with liability, outlined in Section 2.2, is $\omega_{mt}^{*} = \alpha_t\omega_{mt}^{L} + (1-\alpha_t)\omega_{mt}$. For t>K, the optimal portfolio weight is simply $\omega_{mt}^{*} = \omega_{mt}$.

To verify that ω_{mt}^{*} is the optimal solution to (3), we first note that for t≤K, the indirect utility function, combined with the wealth process, can be expressed as:

$$J_t = E_t \frac{\left(W_t\left[\alpha_t \Pi_{\tau=t+1}^{K} R_{K\tau} + (1-\alpha_t)\Pi_{\tau=t+1}^{K} Z_{p\tau} - L\right]\left[\Pi_{\tau=K+1}^{H} Z_{p\tau}\right]\right)^{1-\gamma}}{1-\gamma}$$

And the first order conditions with respect to the decision variables, α_t and ω_{mt} (m=2,...M), are:

$$\partial J_t/\partial\alpha_t = W_t^{1-\gamma} E_t\left(F_t^{-\gamma}\left[\Pi_{\tau=K+1}^{H} Z_{p\tau}\right]^{1-\gamma}\left[\Pi_{\tau=t+1}^{K} R_{K\tau} - \Pi_{\tau=t+1}^{K} Z_{p\tau}\right]\right) = 0 \quad (15)$$

$$\partial J_t/\partial\omega_{mt} = W_t^{1-\gamma} E_t\left(F_t^{-\gamma}(1-\alpha_t)\left[\Pi_{\tau=t+2}^{K} Z_{p\tau}\right]\left[\Pi_{\tau=K+1}^{H} Z_{p\tau}\right]^{1-\gamma}\left[R_{mt+1} - R_{ft+1}\right]\right) = 0 \quad (16)$$

where $F_t = \alpha_t \Pi_{\tau=t+1}^{K} R_{K\tau} + (1-\alpha_t)\Pi_{\tau=t+1}^{K} Z_{p\tau} - L$. We now verify that these conditions are satisfied by our specified α_t and ω_t.

Note that $\alpha_t = LB_t/W_t$ and $\Pi_{\tau=t+1}^{K} R_{K\tau} = 1/B_t$. Therefore,

$$F_t = (1-\alpha_t)\Pi_{\tau=t+1}^{K} Z_{p\tau} \tag{17}$$

Since ω_{mt} is the optimal solution to (1), we can derive a series of first order conditions from the indirect utility function of the problem of (1):

$$E_t\left(Z_{pt+1}^{-\gamma}\left[\Pi_{\tau=t+2}^{H} Z_{p\tau}\right]^{1-\gamma}\left[R_{mt+1} - R_{ft+1}\right]\right) = 0 \tag{18}$$

$$E_t\left(Z_{pt+1}^{-\gamma}\left[\Pi_{\tau=t+2}^{H} Z_{p\tau}\right]^{1-\gamma}\left[R_{mt+1} - R_{Kt+1}\right]\right) = 0 \tag{19}$$

$$E_t\left(Z_{pt+1}^{-\gamma}\left[\Pi_{\tau=t+2}^{H} Z_{p\tau}\right]^{1-\gamma}\left[Z_{pt+1} - R_{Kt+1}\right]\right) = 0 \tag{20}$$

$$E_t\left(\left[\Pi_{\tau=t+1}^{K} Z_{p\tau}\right]^{-\gamma}\left[\Pi_{\tau=K+1}^{H} Z_{p\tau}\right]^{1-\gamma}\left[\Pi_{\tau=t+1}^{K} Z_{p\tau} - \Pi_{\tau=t+1}^{K} R_{Kt+1}\right]\right) = 0 \tag{21}$$

Here we continue to use the notation $Z_{pt} = \omega_{mt-1} R_{mt}$. (19) can be derived by applying (18) to both $R_{mt+1} - R_{ft+1}$ and $R_{Kt+1} - R_{ft+1}$. (20) can be derived from (19) using $Z_{pt} = \omega_{mt-1} R_{mt}$. Finally, (21) is a K-period multiplication of (20).

Then, the first order condition of (16) can be verified using (18) and (17). The first order condition of (15) can be verified using (21) and (17). Thus, for t≤K, we have verified that α_t and ω_t (hence ω_t^*) indeed satisfy the optimality conditions for the problem of (3). For t>K, $\alpha_t = 0$ and $\omega_{mt}^* = \omega_{mt}$. The optimality conditions are apparently satisfied.

Note that the liability immunization component α_t is independent of the risk aversion parameter γ. α_t exists even for an investor with log utility, i.e., $\gamma = 1$. This can be understood by noting that the indirect utility function for $\gamma = 1$ has the following form:

$$J_t = \ln W_t + E_t \ln\left(\alpha_t \Pi_{\tau=t+1}^{K} R_{K\tau} + (1-\alpha_t)\Pi_{\tau=t+1}^{K} Z_{p\tau} - L\right) + E_t \ln\left(\Pi_{\tau=K+1}^{H} Z_{p\tau}\right)$$

The specific way that α_t and ω_t are involved in the second term means the portfolio choice at time t is not affected by distribution of returns beyond time K, but is affected by distribution of returns between time t+1 and time K. Since in this situation K is the last time horizon that log-utility investors care about in their portfolio problem, liability effectively creates a "horizon habitat" for these investors, who otherwise have no horizon habitat.

Finally, we discuss three realistic issues that go beyond the simple model above. First, the liability maturity may exceed the investment horizon, i.e., K>H. In this case, the time-H net wealth is $W_H - PV_H(L)$, where $PV_H(L)$ is the present value of L evaluated at time H. If the investor's objective is to maximize the expected utility from time-H net wealth, then the solution described above still applies. That is, the optimal portfolio involves a component that completely immunizes the interest rate risk of the present value of L, and the remaining portfolio is optimally invested as if there were no liability. Second, investors may have liabilities at different maturities. In such a situation the optimal portfolio involves multiple immunization components, hedging against the interest rate risk of each liability. Third, financial institutions typically have a rolling maturities of liabilities. As they pay off shorter-maturity liabilities, at the same time they incur new liabilities at longer maturities. Consequently, the liability maturity structure or duration of a financial institution remains relatively stable over time, rather than being shortened. This feature is beyond our simple model but should nonetheless be taken into account in empirical analysis.

5.1 A.3. Quarterly Corporate Bond Holdings

We use corporate bond holdings and transactions data from Schedule D of insurance companies' annual statements provided by the NAIC to construct individual insurers' quarterly corporate bond holdings.[19] As mentioned earlier, Schedule D includes trading dates for all the transactions. We obtain quarterly holdings calculated based on i) long-term bonds owned on December 31 of a given year; ii) long-term bonds acquired within a year; iii) long-term bonds sold, redeemed or otherwise disposed in a year; and iv) long-term bonds acquired during the year and fully disposed in a year.

Part of this exercise involves computing the par value of each individual corporate bond held by every insurer in our sample at the end of each quarter. We perform this task by sequentially estimating quarterly holdings, quarter by quarter in a given year. More specifically, we use the par value of each individual bond that an insurer purchases minus the par value of the same bond that the insurer sells in a quarter to compute the net trading of a quarter. Then the insurer's holdings of an individual bond in the first quarter of a year are the sum of the insurer's holdings at the end of the previous year and the net trading in the first quarter. The second quarter holdings are the sum of the holdings of the first quarter and the net trading in the second quarter. Holdings at the end of third and fourth quarters are estimated similarly.

Like other commercial databases, there are errors in Schedule D data. To address this problem, we compute a discrepancy ratio, measured as the absolute value of the difference between the year-end holdings reported in Schedule D of a year and the estimated fourth-quarter holdings in the same year scaled by the average of these two holdings. We consider the observation of a bond in a year as an outlier if its discrepancy ratio in the fourth quarter of the year exceeds 0.1 and remove such observations from the sample. Moreover, when an insurer has more than 10% of its holdings removed in a year, we drop the entire portfolio of the insurer from the sample in that year.

Before any cleanse, there are 1,945,926 insurer-bond-year observations corresponding to 3,461 unique life and nonlife insurers in the quarterly corporate bond holdings data set over the sample period from 2003 to 2009. Imposing the constraint on the discrepancy ratio reduces the sample to 1,843,687 insurer-bond-year observations and 3,226 unique insurers.

[19]The Schedule D data include holdings and transactions information for all types of financial assets held by insurance companies, such as corporate, municipal, and government bonds, stocks, and real estate, among others. Bonds included in the database fall into nine categories: i) U.S. government bonds, ii) all other government bonds, iii) States, territories and possessions, iv) political subdivisions of States, territories and possessions, v) special revenue and special assessment obligations and all non-guaranteed obligations of agencies and authorities of governments and their political subdivisions, vi) public utilities, vii) industrial and miscellaneous, viii) credit tenant loans, and ix) parents, subsidiaries and affiliates bonds. Within each category, bonds are further separated into issuer obligations and mortgage or asset backed securities. We consider issuer obligations of public utilities, industrial and miscellaneous bonds, and bonds issued by parents, subsidiaries and affiliates as corporate bonds.

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Table 1: Insurer Characteristics

This table reports the number of insurers in the sample, the average total assets, and the following asset items as fractions of total assets: invested assets, the dollar amount of stock and bond holding, the dollar amount of bond holding, and the dollar amount of government bond holding. In addition, we report a set of insurers' operating and financial characteristics. The liability ratio LR is the ratio of claim liabilities to invested assets. CDURL, CDURS, and CDURC are the level, slope, and curvature durations of insurers' operating liabilities. PctLife is the percentage of insurance premiums generated by life insurance policies. IND is the percentage of insurers that are not affiliated with parent groups or holding companies. NOD is the percentage of insurers that do not pay dividends. Age is the median age of insurers, calculated as the number of years since a firm's inception. CAP is the average capital adequacy ratio, calculated as total adjusted capital relative to an insurer's authorized control capital level. LR, PctLife, IND, and CAP are expressed in percentage points. CDURL, CDURS, and CDURC are expressed in years. We report the statistics in year 1998, 2002, 2006, 2009, and 2011. The row "All" reports the average statistics across all the sample years from 1998 to 2011, except that the number of insurers is the unique number of insurers during the entire sample period. The last two rows report the cross-sectional standard deviation (CS STD) and time-series standard deviation (TS STD) of the variables respectively. Panel A reports statistics for property and casualty (PC) insurers and Panel B reports statistics for life insurers.

Panel A: Property and Casualty (PC) Insurers

Year	Number of Insurers	Total Assets ($m)	As Fraction of Total Assets (%)				Operating and Financial Characteristics							
			Invested Assets	Bonds & Stocks	Bonds	Gov. Bonds	LR	CDURL	CDURS	CDURC	IND	NOD	Age	CAP
1998	888	751.43	89.15	79.44	65.27	24.06	42.11	2.29	1.36	0.55	32.77	81.47	30	11.41
2002	927	858.14	82.24	70.30	59.96	22.11	38.42	2.31	1.37	0.56	28.80	75.84	30	13.28
2006	968	1,103.81	84.24	73.58	62.66	22.57	37.93	2.23	1.34	0.53	30.61	83.25	30	11.60
2009	872	1,304.15	83.87	73.27	63.79	20.27	37.39	2.27	1.36	0.55	26.15	80.39	32	13.45
2011	740	1,584.67	83.37	73.67	62.95	19.30	39.50	2.39	1.40	0.58	22.30	80.27	35	13.94
All	1,410	1,071.54	84.53	74.06	62.74	21.61	38.26	2.28	1.10	0.56	29.19	79.69	31	12.56
CS STD	-	4,616.24	11.54	14.92	18.13	19.63	32.37	1.00	0.16	0.21	-	-	45.69	21.37
TS STD	-	230.54	5.71	8.59	9.02	8.89	8.62	0.34	0.05	0.07	-	-	4.34	6.17

Panel B: Life Insurers

Year	Number of Insurers	Total Assets ($m)	As Fraction of Total Assets (%)				Operating and Financial Characteristics					
			Invested Assets	Bonds & Stocks	Bonds	Gov. Bonds	LR	PctLife	IND	NOD	Age	CAP
1998	541	4,525.03	90.38	74.17	67.13	17.10	61.65	63.77	34.32	79.78	37	38.52
2002	551	5,593.72	90.44	74.51	69.40	17.46	66.49	64.96	33.27	71.45	48	45.65
2006	513	8,408.51	89.93	74.77	69.28	18.91	66.87	65.32	33.93	76.53	53	36.74
2009	437	10,236.69	89.96	73.88	69.97	15.55	69.83	64.78	32.02	78.65	56	26.30
2011	388	12,875.99	88.43	72.77	69.02	16.28	68.80	66.31	29.83	82.46	57	26.76
All	691	7,718.28	89.89	74.23	68.95	16.98	65.92	64.78	33.19	72.30	50	20.40
CS STD	-	24,117.83	22.21	23.37	23.33	21.27	29.20	38.60	-	-	38.12	26.53
TS STD	-	1,771.35	1.94	7.36	8.18	7.63	9.88	4.40	-	-	3.95	10.63

Table 2: Durations and Weights of Insurers' Aggregate Government Bond Portfolios

Panel A reports the the attributes of the aggregate government bond portfolios of PC insurers and life insurers. The portfolio attributes include the three Nelson-Siegel portfolio duration measures (DURL, DURS, and DURC, expressed in years) and the cash flow weights of the aggregate portfolios (ω, expressed in percentage points) in 11 maturity bins. We classify the bond cash flows of a portfolio into 10 maturity bins that each has a three-year maturity span, and a 11th bin for cash flows maturing beyond 30 years. Panel B reports the elasticities of aggregate portfolio durations with respect to the interest rate factors. The elasticities are estimated coefficients of time series regressions, where the dependent variable is one of the three Nelson-Siegel portfolio duration measures (DURL, DURS, and DURC). The explanatory variable is the corresponding Nelson-Siegel level, slope, and curvature factors. The t-statistics reported in parenthesis are computed using the Newey-West procedure with a 3-year lag. The reported elasticities are expressed in percentage points. The sample period is from 1998 to 2011.

Panel A: Attributes of Insurers' Aggregate Bond Portfolios

	PC Insurers			Life Insurers		
	Mean	Median	Std. Dev	Mean	Median	Std. Dev
DURL	5.98	5.90	0.50	10.91	11.03	0.99
DURS	1.24	1.24	0.01	1.31	1.32	0.02
DURC	1.02	1.02	0.02	1.20	1.21	0.05
ω1 (0, 3](x100)	28.40	28.50	3.72	10.24	10.07	2.47
ω2 (3, 6](x100)	27.14	26.06	3.70	11.20	10.26	2.42
ω3 (6, 9](x100)	16.45	16.64	2.26	11.17	10.83	1.60
ω4 (9, 12](x100)	7.37	7.53	1.38	11.40	9.96	3.70
ω5 (12, 15](x100)	5.16	4.67	1.61	10.98	9.13	4.22
ω6 (15, 18](x100)	4.89	4.67	1.51	11.08	11.02	1.99
ω7 (18, 21](x100)	4.94	4.53	2.80	10.73	10.80	2.58
ω8 (21, 24](x100)	2.58	2.71	1.52	6.82	7.28	2.37
ω9 (24, 27](x100)	1.64	1.65	0.96	6.80	6.46	1.84
ω10 (27, 30](x100)	1.32	1.35	0.80	9.01	8.06	4.50
ω11 (>30)(x100)	0.11	0.02	0.16	0.57	0.56	0.31

Panel B: Elasticities of Aggregate Portfolio Durations to Interest Rate Factors

	PC Insurers			Life Insurers		
	Level	Slope	Curvature	Level	Slope	Curvature
DURL(x100)	7.37			-52.50		
	(1.09)			(-2.68)		
DURS(x100)		-0.29			-0.17	
		(-1.46)			(-1.14)	
DURC(x100)			-0.09			-0.29
			(-0.80)			(-1.21)

Table 3: The Cross-section of Portfolio Durations and Portfolio Weights

This table reports the cross-sectional statistics of individual insurers' government bond portfolio attributes. The portfolio attributes include the three Nelson-Siegel portfolio duration measures (DURL, DURS, and DURC, expressed in years), and portfolio weights (ω, expressed in percentage points) in 11 maturity bins. The cross-sectional statistics include the mean, median, the 10th and 90th percentiles, and the standard deviation; they are computed in each year and then averaged over years. We also report the time series standard deviations of the portfolio attributes, which are estimated for each insurers first and then averaged across insurers. We report the statistics for PC insurers and life insurers separately. The sample period is from 1998 to 2011.

	PC Insurers						Life Insurers					
	Cross-sectional distribution					Time-Series	Cross-sectional distribution					Time-Series
	Mean	Median	P10	P90	Std. Dev	Std. Dev	Mean	Median	P10	P90	Std. Dev	Std. Dev
DURL	4.83	4.36	2.34	7.88	2.34	1.45	6.77	6.06	2.78	11.66	3.68	1.83
DURS	1.17	1.19	0.99	1.30	0.13	0.10	1.21	1.25	1.04	1.32	0.13	0.09
DURC	0.91	0.93	0.61	1.17	0.22	0.16	1.00	1.06	0.68	1.23	0.22	0.14
ω1(x100)	41.23	36.56	11.53	80.05	25.53	19.61	30.47	21.43	7.72	69.30	24.85	15.83
ω2(x100)	27.88	24.67	6.01	54.95	19.31	17.07	22.41	17.02	4.56	48.23	18.12	14.46
ω3(x100)	15.05	10.14	0.00	37.56	15.77	12.51	15.10	10.98	0.27	35.55	14.53	11.42
ω4(x100)	5.57	1.48	0.00	16.69	9.27	6.54	8.56	5.10	0.00	22.54	10.82	7.81
ω5(x100)	3.52	0.07	0.00	10.88	7.84	3.93	6.45	2.49	0.00	18.64	10.09	5.98
ω6(x100)	2.20	0.00	0.00	6.77	5.79	2.60	4.91	0.95	0.00	14.54	9.30	4.84
ω7(x100)	1.77	0.00	0.00	5.10	5.31	2.36	4.35	0.13	0.00	13.54	9.21	4.92
ω8(x100)	1.11	0.00	0.00	2.95	3.78	1.61	2.87	0.00	0.00	8.93	7.05	3.75
ω9(x100)	0.93	0.00	0.00	2.01	3.70	1.51	2.44	0.00	0.00	7.40	7.14	3.35
ω10(x100)	0.74	0.00	0.00	0.90	3.54	1.36	2.43	0.00	0.00	7.51	7.47	3.48
ω11(x100)	0.05	0.00	0.00	0.00	1.00	0.15	0.20	0.00	0.00	0.00	1.62	0.41

Table 4: Persistence of Portfolio Durations and Portfolio Weights

This table reports the results of Fama-MacBeth cross-sectional regressions that analyze the persistence of portfolio attributes. The dependent variables are the three portfolio duration measures (DURL, DURS, DURC) as well as the portfolio weights (ω1-ω10) of the 10 maturity bins. The explanatory variables are the lagged portfolio durations or portfolio weights, with lags of 1 to 5 years. The regressions are performed in each year across insurers. We report the time series means of the coefficients and the time series t-statistics (in parentheses). Panels A and B are for PC insurers and life insurers separately. The time series t-statistics are computed using the Newey-West procedure with a three-year lag. The sample period is from 1998 to 2011.

	Dependent Variable (in year t)												
	DURL	DURS	DURC	ω1	ω2	ω3	ω4	ω5	ω6	ω7	ω8	ω9	ω10
	Panel A: PC Insurers												
t-1	0.92	0.85	0.88	0.88	0.83	0.87	0.78	0.91	0.90	0.88	0.89	0.87	0.81
	(31.00)	(28.35)	(27.10)	(23.71)	(20.07)	(20.61)	(20.82)	(19.55)	(18.94)	(19.63)	(14.94)	(10.08)	(12.06)
t-2	0.86	0.74	0.79	0.78	0.66	0.75	0.62	0.82	0.80	0.78	0.78	0.77	0.67
	(27.79)	(23.69)	(16.12)	(22.29)	(19.84)	(18.85)	(14.25)	(20.27)	(10.04)	(15.08)	(14.30)	(7.78)	(7.92)
t-3	0.81	0.63	0.70	0.68	0.52	0.63	0.51	0.74	0.70	0.68	0.69	0.66	0.56
	(26.64)	(16.22)	(15.87)	(19.78)	(18.54)	(14.21)	(10.26)	(10.23)	(7.08)	(7.90)	(6.30)	(10.85)	(4.70)
t-4	0.77	0.56	0.65	0.60	0.39	0.53	0.45	0.67	0.61	0.60	0.60	0.57	0.49
	(28.77)	(11.62)	(19.96)	(16.75)	(13.91)	(15.50)	(9.09)	(14.90)	(11.59)	(12.01)	(11.68)	(8.23)	(3.41)
t-5	0.73	0.51	0.60	0.55	0.31	0.48	0.40	0.62	0.57	0.56	0.56	0.52	0.44
	(25.28)	(16.85)	(14.24)	(14.91)	(10.18)	(13.78)	(8.97)	(13.52)	(9.74)	(8.92)	(11.17)	(7.89)	(3.81)
	Panel B: Life Insurers												
t-1	0.94	0.87	0.90	0.89	0.84	0.85	0.78	0.90	0.90	0.89	0.91	0.88	0.84
	(27.77)	(33.08)	(35.87)	(28.20)	(16.74)	(13.11)	(14.51)	(16.11)	(16.29)	(18.71)	(19.25)	(10.44)	(4.79)
t-2	0.90	0.77	0.82	0.80	0.70	0.72	0.63	0.80	0.80	0.78	0.82	0.77	0.73
	(26.21)	(26.26)	(29.76)	(19.02)	(16.95)	(19.02)	(10.71)	(15.31)	(11.26)	(14.51)	(9.97)	(6.87)	(3.12)
t-3	0.86	0.68	0.76	0.73	0.58	0.60	0.52	0.72	0.71	0.68	0.74	0.67	0.63
	(20.08)	(18.54)	(20.11)	(20.67)	(14.59)	(18.45)	(16.34)	(18.69)	(17.00)	(17.19)	(14.42)	(7.78)	(3.88)
t-4	0.83	0.62	0.71	0.67	0.47	0.50	0.46	0.63	0.63	0.58	0.66	0.58	0.56
	(22.80)	(20.80)	(22.80)	(18.84)	(16.00)	(10.80)	(16.18)	(18.43)	(9.75)	(8.49)	(11.59)	(12.89)	(3.28)
t-5	0.80	0.57	0.67	0.62	0.40	0.44	0.40	0.57	0.58	0.53	0.60	0.52	0.51
	(20.88)	(16.65)	(16.30)	(16.06)	(11.94)	(9.66)	(14.76)	(14.44)	(8.41)	(4.75)	(6.35)	(8.03)	(2.14)

Table 5: Effect of Liability and Risk Aversion on Portfolio Durations

The table reports the results of cross-sectional regressions for the liability habitat effect and risk aversion effect. The dependent variables include the three portfolio duration measures DURL, DURS, and DURC. The explanatory variables include the liability duration proxies and risk aversion proxies. The liability proxies include three liability durations for PC insurers (CDURL, CDURS, and CDURC) and PctLife for life insurers. The risk aversion proxies include a dummy for non-affiliated insurers (INDEP), a dummy for non-dividend payers (NODIV), the negative of log firm age (YOUNG), the negative of log capital adequacy ratio (LOWCAP). The dependent and explanatory variables are the time-averaged values for individual insurers. We perform univariate regressions, using one of the explanatory variable each time. Panel A reports the results for PC insurers and Panel B reports the results for life insurers.

Panel A: PC Insurers

	Explanatory variables						
	CDURL	CDURS	CDURC	INDEP	NODIV	YOUNG	LOWCAP
DURL	0.30			-0.40	-0.66	-0.15	0.02
	(2.97)			(-3.66)	(-4.08)	(-3.20)	(0.35)
DURS(x100)		2.12		-2.28	-2.82	-0.40	0.62
		(1.53)		(-4.47)	(-3.68)	(-1.84)	(2.19)
DURC(x100)			4.64	-3.89	-5.48	-1.10	0.85
			(1.72)	(-4.26)	(-4.01)	(-2.82)	(1.69)

Panel B: Life Insurers

	Explanatory variables				
	PctLife	INDEP	NODIV	YOUNG	LOWCAP
DURL	1.31	-1.08	-2.75	-0.57	-0.73
	(4.30)	(-4.15)	(-5.60)	(-4.40)	(-6.46)
DURS(x100)	4.44	-1.67	-9.16	-2.20	-2.17
	(4.87)	(-2.08)	(-6.19)	(-3.73)	(-6.35)
DURC(x100)	8.81	-3.47	-18.40	-4.52	-4.20
	(5.11)	(-2.29)	(-6.60)	(-3.67)	(-6.51)

Table 6: The Cross-section of Portfolio Elasticity to Interest Rate Factors

This table reports cross-sectional statistics on portfolio elasticities to interest rate factors. The portfolio elasticities are the coefficients of regressing an individual insurers' adjusted portfolio durations as well as their portfolio weights in the 10 maturity bins onto the corresponding level, slope, and curvature factors. The adjusted portfolio durations are durations of the active portfolio deviations from average portfolio weights. The cross-sectional statistics include the mean, median, the 10th and 90th percentiles, and standard deviation of the portfolio elasticities. The median elasticities for portfolio weights in certain maturity bins (above #4 for PC insurers and above #5 for life insurers) are not reported because the median portfolio weights at these bins are always close to zero. Panels A, B, and C are for the elasticities with respect to the three interest rate factors respectively. The estimated elasticities are percentage points. The bootstrapped p-values (p) are reported in the parentheses under the corresponding sample statistics.

	PC Insurers					Life Insurers				
	Mean	Median	P10	P90	Std. Dev	Mean	Median	P10	P90	Std. Dev
	Panel A: Level									
DURL*(x100)	19.93	13.52	-97.51	159.31	125.77	12.79	17.86	-166.32	162.24	151.40
p	(0.08)	(0.17)	(0.07)	(0.91)	(0.93)	(0.10)	(0.13)	(0.11)	(0.90)	(0.96)
ω1(x100)	-1.37	-0.78	-17.61	13.70	14.15	0.25	0.61	-13.84	13.99	11.50
p	(0.85)	(0.82)	(0.40)	(0.94)	(0.87)	(0.39)	(0.14)	(0.35)	(0.61)	(0.77)
ω2(x100)	-0.49	-0.36	-12.21	11.80	11.12	1.21	0.53	-8.62	12.19	9.35
p	(0.71)	(0.81)	(0.12)	(0.88)	(0.94)	(0.09)	(0.21)	(0.07)	(0.48)	(0.79)
ω3(x100)	0.53	0.00	-8.08	9.87	8.47	-1.05	-0.80	-9.48	7.56	7.74
p	(0.15)	(0.81)	(0.04)	(0.76)	(0.92)	(0.89)	(0.91)	(0.38)	(0.90)	(0.83)
ω4(x100)	-0.36	-	-5.14	4.16	5.44	-1.42	-0.74	-6.59	3.97	5.44
p	(0.90)	(0.99)	(0.49)	(0.86)	(0.80)	(0.88)	(0.93)	(0.53)	(0.90)	(0.85)
ω5(x100)	0.37	-	-2.12	3.90	4.13	-0.12	-	-5.09	5.01	5.37
p	(0.21)	-	(0.12)	(0.27)	(0.85)	(0.54)	(0.84)	(0.48)	(0.53)	(0.68)
ω6(x100)	0.28	-	-1.59	2.52	3.00	0.41	-	-3.40	4.79	4.64
p	(0.13)	-	(0.23)	(0.26)	(0.83)	(0.14)	-	(0.19)	(0.33)	(0.75)
ω7(x100)	0.35	-	-1.03	2.26	2.87	-0.01	-	-4.05	4.17	5.40
p	(0.05)	-	(0.11)	(0.17)	(0.80)	(0.49)	-	(0.44)	(0.52)	(0.62)
ω8(x100)	0.29	-	-0.34	1.62	2.38	0.22	-	-2.59	3.36	3.80
p	(0.16)	-	(0.11)	(0.21)	(0.78)	(0.37)	-	(0.33)	(0.50)	(0.85)
ω9(x100)	0.29	-	-0.11	1.63	3.66	0.41	-	-1.68	3.58	3.35
p	(0.17)	-	(0.09)	(0.15)	(0.34)	(0.13)	-	(0.20)	(0.20)	(0.82)
ω10(x100)	0.11	-	-0.19	1.09	2.07	0.09	-	-2.43	2.86	3.87
p	(0.35)	-	(0.27)	(0.21)	(0.72)	(0.45)	-	(0.46)	(0.46)	(0.78)

	PC Insurers					Life Insurers				
	Mean	Median	P10	P90	Std. Dev	Mean	Median	P10	P90	Std. Dev
					Panel B: Slope					
DURS*(x100)	-0.97	-0.76	-3.60	1.34	2.31	-0.67	-0.48	-2.71	1.11	1.68
p	(0.96)	(0.95)	(0.20)	(1.00)	(1.00)	(0.93)	(0.92)	(0.15)	(1.00)	(1.00)
$\omega 1$(x100)	0.77	0.49	-4.17	5.75	4.44	0.58	0.38	-3.59	4.66	3.36
p	(0.12)	(0.13)	(0.00)	(0.98)	(1.00)	(0.12)	(0.19)	(0.01)	(0.91)	(0.96)
$\omega 2$(x100)	-0.37	-0.32	-5.02	4.07	3.88	-0.53	-0.33	-4.43	2.74	3.00
p	(0.83)	(0.92)	(0.02)	(0.99)	(1.00)	(0.89)	(0.90)	(0.16)	(1.00)	(1.00)
$\omega 3$(x100)	-0.07	-	-3.53	3.22	3.09	0.11	0.05	-2.76	2.71	2.45
p	(0.64)	-	(0.02)	(1.00)	(1.00)	(0.38)	(0.38)	(0.01)	(0.99)	(1.00)
$\omega 4$(x100)	-0.06	-	-1.51	1.39	1.63	-0.11	-0.01	-1.84	1.47	1.61
p	(0.70)	-	(0.01)	(1.00)	(1.00)	(0.51)	(0.57)	(0.05)	(0.98)	(1.00)
$\omega 5$(x100)	-0.25	-	-1.31	0.47	1.29	-0.20	-0.03	-1.88	1.10	1.64
p	(0.89)	-	(0.32)	(1.00)	(1.00)	(0.65)	(0.87)	(0.19)	(0.97)	(1.00)
$\omega 6$(x100)	-	-	-0.58	0.72	1.04	0.01	-	-1.18	1.10	1.64
p	-	-	(0.03)	(0.90)	(0.99)	(0.52)	-	(0.01)	(0.95)	(1.00)
$\omega 7$(x100)	-0.03	-	-0.51	0.52	1.01	0.06	-	-1.19	1.44	1.53
p	(0.65)	-	(0.17)	(0.89)	(0.99)	(0.41)	-	(0.04)	(0.94)	(1.00)
$\omega 8$(x100)	-	-	-0.21	0.47	1.14	0.24	-	-0.43	1.41	1.18
p	-	-	(0.17)	(0.56)	(0.79)	(0.17)	-	(0.00)	(0.62)	(1.00)
$\omega 9$(x100)	-0.01	-	-0.29	0.21	1.22	-	-	-0.78	0.67	1.06
p	(0.53)	-	(0.43)	(0.71)	(0.79)	-	-	(0.18)	(0.91)	(1.00)
$\omega 10$(x100)	0.02	-	-0.17	0.19	0.57	-0.16	-	-1.08	0.35	1.03
p	(0.53)	-	(0.49)	(0.63)	(1.00)	(0.71)	-	(0.43)	(0.96)	(1.00)
					Panel C: Curvature					
DURC*(x100)	-0.50	-0.45	-3.05	2.17	2.27	-0.47	-0.43	-2.70	1.62	1.75
p	(0.89)	(0.91)	(0.33)	(0.99)	(0.96)	(0.95)	(0.97)	(0.45)	(0.99)	(0.96)
$\omega 1$(x100)	0.16	0.15	-3.09	3.18	2.70	0.27	0.20	-2.32	2.85	2.09
p	(0.31)	(0.23)	(0.09)	(0.87)	(0.96)	(0.06)	(0.07)	(0.05)	(0.71)	(0.95)
$\omega 2$(x100)	-0.25	-0.16	-2.98	2.36	2.32	-0.17	-0.12	-2.42	1.92	1.78
p	(0.92)	(0.94)	(0.30)	(0.96)	(0.95)	(0.76)	(0.78)	(0.36)	(0.93)	(0.93)
$\omega 3$(x100)	0.09	0.04	-1.97	2.07	1.76	-0.04	0.06	-1.77	1.54	1.47
p	(0.21)	(0.10)	(0.12)	(0.82)	(0.94)	(0.56)	(0.30)	(0.16)	(0.94)	(0.95)
$\omega 4$(x100)	-0.03	-	-0.90	0.78	0.95	-0.06	-	-1.20	0.85	1.04
p	(0.67)	-	(0.13)	(0.96)	(0.96)	(0.57)		(0.32)	(0.91)	(0.95)
$\omega 5$(x100)	-0.08	-	-0.63	0.38	0.78	-0.08	-	-0.97	0.67	0.94
p	(0.78)	-	(0.42)	(0.95)	(0.95)	(0.61)	-	(0.39)	(0.89)	(0.95)
$\omega 6$(x100)	0.04	-	-0.31	0.44	0.54	0.04	-	-0.66	0.91	0.96
p	(0.27)	-	(0.15)	(0.48)	(0.95)	(0.37)	-	(0.10)	(0.51)	(0.82)
$\omega 7$(x100)	0.03	-	-0.19	0.36	0.52	0.07	-	-0.64	0.89	0.86
p	(0.26)	-	(0.05)	(0.45)	(0.94)	(0.19)	-	(0.08)	(0.50)	(0.97)
$\omega 8$(x100)	0.05	-	-0.08	0.31	0.43	0.14	-	-0.23	0.78	0.70
p	(0.21)	-	(0.11)	(0.27)	(0.93)	(0.14)	-	(0.01)	(0.41)	(0.95)
$\omega 9$(x100)	-0.03	-	-0.14	0.14	0.53	-0.02	-	-0.51	0.37	0.70
p	(0.67)	-	(0.43)	(0.58)	(0.80)	(0.60)	-	(0.44)	(0.87)	(0.87)
$\omega 10$(x100)	0.01	-	-0.05	0.16	0.35	-0.15	-	-0.67	0.34	0.87
p	(0.42)	-	(0.31)	(0.40)	(0.97)	(0.88)	-	(0.66)	(0.76)	(0.72)

Table 7: Effect of Liability and Risk Aversion on Portfolio Duration Elasticities

This table reports the result of the cross-sectional regressions for the effect of liability and risk aversion on portfolio elasticities. The dependent variables are the absolute elasticities of insurers' adjusted portfolio durations to the corresponding interest rate factor (level, slope, and curvature). The adjusted portfolio durations are durations of the active portfolio deviations from average portfolio weights. The explanatory variables include the liability ratio (LR) and the four proxies for risk aversion —a dummy for non-affiliated insurers (INDEP), a dummy for non-dividend payers (NODIV), the negative of log firm age (YOUNG), the negative of log capital adequacy ratio (LOWCAP). We perform univariate regressions, using one explanatory variable at a time. The coefficients are in percentage points and the t-statistics are reported in the parentheses.

	Dependent variable: absolute duration elasticities to interest rate factors					
	PC Insurers			Life Insurers		
	Level	Slope	Curvature	Level	Slope	Curvature
LR	-1.88	-0.41	-0.32	-12.26	-0.49	-0.36
	(-1.90)	(-1.60)	(-2.38)	(-2.13)	(-2.83)	(-2.13)
INDEP	-5.14	-0.03	0.03	-39.58	0.05	-0.08
	(-1.94)	(-2.66)	(2.90)	(-4.29)	(0.43)	(-0.78)
NODIV	-18.75	-0.29	0.22	-2.26	0.57	-0.25
	(-2.29)	(-1.99)	(1.68)	(-1.71)	(2.84)	(-1.30)
YOUNG	-1.59	0.09	0.09	-14.08	0.07	0.03
	(-0.69)	(2.32)	(2.32)	(-2.88)	(0.58)	(0.50)
LOWCAP	-3.11	-0.15	-0.02	-9.55	-0.17	-0.16
	(-1.02)	(-1.27)	(-1.93)	(-2.34)	(-3.65)	(-3.52)

Table 8: The Effect of Habitat and Quantitative Easing

The table reports the results of the habitat effects when the Federal reserve implements the quantitative easing program (Q1 of 2009 through Q4 of 2011). Panel A reports the effects of liability and horizon habitats on the three portfolio duration measures (DURL, DURS, and DURC). The explanatory variables include the liability duration proxies and risk aversion proxies. The liability proxies include three liability durations for PC insurers (CDUR) and PctLife for life insurers. The risk aversion proxies include a dummy for non-affiliated insurers (INDEP), a dummy for non-dividend payers (NODIV), the negative of log firm age (YOUNG), the negative of log capital adequacy ratio (LOWCAP). Panel B reports the result of the cross-sectional regressions for the effect of liability and risk aversion on portfolio elasticities. The dependent variables are the absolute elasticities of insurers' adjusted portfolio durations to the corresponding interest rate factor (level, slope, and curvature). The adjusted portfolio durations are durations of the active portfolio deviations from average portfolio weights. The explanatory variables include the liability ratio (LR) and the four proxies for risk aversion used in Panel A. The coefficients are in percentage points and the t-statistics are reported in the parentheses. In both panels, we perform univariate regressions, using one explanatory variable at a time. Panel C reports the difference in the absolute value of portfolio duration sensitivities to interest rate factors for the long- and short-term bonds around Quantitative easing (the value in QE minus the value prior to QE). We consider a bond longer than 5 years to maturity as a long term bond.

Panel A: Habitats and Portfolio Durations

	PC Insurers					Life Insurers				
	CDUR	INDEP	NODIV	YOUNG	LOWCAP	PctLife	INDEP	NODIV	YOUNG	LOWCAP
DURL	0.14	-0.33	-0.47	-0.17	0.13	3.61	-1.25	-2.91	-0.95	-0.82
	(2.33)	(-3.07)	(-3.44)	(-3.02)	(0.36)	(6.35)	(-4.38)	(-5.92)	(-5.56)	(-5.13)
DURS	0.02	-1.43	-1.63	0.26	0.18	0.10	-2.43	-8.30	-2.75	-3.26
	(1.03)	(-3.70)	(-2.36)	(-1.63)	(0.76)	(5.64)	(-2.36)	(-4.39)	(-4.06)	(-4.33)
DURC	0.02	-2.75	-3.16	-0.97	0.43	0.20	-2.68	-3.68	-12.64	-3.52
	(1.24)	(-3.18)	(-2.40)	(-3.15)	(0.95)	(6.53)	(-3.22)	(-5.84)	(-4.67)	(-5.81)

Panel B: Effect of Liability and Risk Aversion on Portfolio Duration Elasticities

	Dependent variable: absolute duration elasticities to interest rate factors					
	PC Insurers			Life Insurers		
	Level	Slope	Curvature	Level	Slope	Curvature
LR	-1.82	-0.22	-0.34	-9.86	-0.54	-0.47
	(-0.94)	(-1.42)	(-1.99)	(-2.27)	(-3.38)	(-2.82)
INDEP	-8.25	-0.04	0.04	-32.40	0.05	-0.09
	(-2.15)	(-0.73)	(0.35)	(-3.64)	(0.82)	(-0.75)
NODIV	-11.44	-0.23	0.72	-2.72	0.59	-0.08
	(-1.80)	(-1.43)	(1.92)	(-1.88)	(1.35)	(-1.61)
YOUNG	-2.44	0.08	0.13	-17.66	0.12	0.04
	(-1.78)	(2.19)	(1.38)	(-2.96)	(1.49)	(0.53)
LOWCAP	-4.76	-0.09	-0.12	-6.77	-0.15	-0.12
	(-1.93)	(-1.45)	(-2.23)	(-1.73)	(-3.01)	(-2.82)

Panel C: Changes of Portfolio Duration Elasticities around Quantitative Easing

	PC Insurers			Life Insurers		
	Level	Slope	Curvature	Level	Slope	Curvature
LT Bonds (x100)	3.25	0.07	0.14	-1.79	0.05	0.10
	(4.58)	(4.63)	(3.36)	(-1.81)	(3.63)	(3.75)
ST Bonds (x100)	-0.24	0.05	0.71	-2.45	0.24	0.14
	(-0.93)	(-0.34)	(2.15)	(-3.04)	(1.31)	(4.13)

Table 9: Habitat Effects Using Entire Bond Portfolios

The table reports the results of the habitat effects based on the analysis using insurers' entire bond portfolios. Panel A reports the effects of liability and horizon habitats on the three portfolio duration measures (DURL, DURS, and DURC). The explanatory variables include the liability duration proxies and risk aversion proxies. The liability proxies include three liability durations for PC insurers (CDUR, including CDURL, CDURS, CDURC) and PctLife for life insurers. The risk aversion proxies include a dummy for non-affiliated insurers (INDEP), a dummy for non-dividend payers (NODIV), the negative of log firm age (YOUNG), the negative of log capital adequacy ratio (LOWCAP). Panel B reports the result of the cross-sectional regressions for the effect of liability and risk aversion on portfolio elasticities. The dependent variables are the absolute elasticities of insurers' adjusted portfolio durations to the corresponding interest rate factor (level, slope, and curvature). The adjusted portfolio durations are durations of the active portfolio deviations from average portfolio weights. The explanatory variables include the liability ratio (LR) and the four proxies for risk aversion used in Panel A. The coefficients are in percentage points and the t-statistics are reported in the parentheses. In both panels, we perform univariate regressions, using one explanatory variable at a time.

Panel A: Habitats and Portfolio Durations

	PC Insurers					Life Insurers				
	CDUR	INDEP	NODIV	YOUNG	LOWCAP	PctLife	INDEP	NODIV	YOUNG	LOWCAP
DURL	0.83	-1.20	-1.36	-0.34	-0.27	1.60	-1.41	-2.89	-0.93	-0.88
	(7.60)	(-10.17)	(-7.49)	(-6.65)	(-4.12)	(5.97)	(-6.10)	(-6.87)	(-6.52)	(-6.94)
DURS	0.06	-0.04	-0.04	-0.01	-0.01	0.04	-0.03	-0.09	-0.02	-0.02
	(5.08)	(-9.39)	(-6.39)	(-5.45)	(-1.90)	(5.87)	(-5.27)	(-7.91)	(-5.87)	(-6.66)
DURC	0.12	-0.08	-0.08	-0.02	-0.01	0.09	-0.07	-0.18	-0.05	-0.05
	(5.03)	(-9.76)	(-6.94)	(-6.62)	(-2.04)	(6.22)	(-5.36)	(-8.33)	(-6.40)	(-6.68)

Panel B: Effect of Liability and Risk Aversion on Portfolio Duration Elasticities

	Dependent variable: absolute duration elasticities to interest rate factors					
	PC Insurers			Life Insurers		
	Level	Slope	Curvature	Level	Slope	Curvature
LR	-17.22	-0.57	-0.71	-36.84	-1.75	-1.68
	(-1.35)	(-3.43)	(-2.62)	(-2.63)	(-4.54)	(-6.28)
INDEP	-16.31	0.18	0.27	-4.86	0.07	0.18
	(-2.65)	(-0.73)	(2.05)	(-0.60)	(0.32)	(1.15)
NODIV	1.69	0.21	0.72	35.17	1.09	1.12
	(0.18)	(-1.72)	(3.58)	(2.42)	(2.68)	(3.92)
YOUNG	-1.93	0.10	0.16	5.96	0.24	0.23
	(-0.74)	(3.06)	(2.94)	(1.22)	(1.73)	(2.39)
LOWCAP	-5.34	-0.05	-0.19	-12.15	-0.57	-0.46
	(-1.59)	(-1.13)	(-2.60)	(-2.75)	(-4.70)	(-5.35)

Figure 1: Yield Curve and Nelson-Siegel Term Structure Factors

Panels A to D plot the actual yield curves and fitted Nelson-Siegel yield curves for four representative years: 1998, 2002, 2006, and 2011. Panels E to G plot the three Nelson-Siegel interest rate factors (level, slope, and curvature) over time.

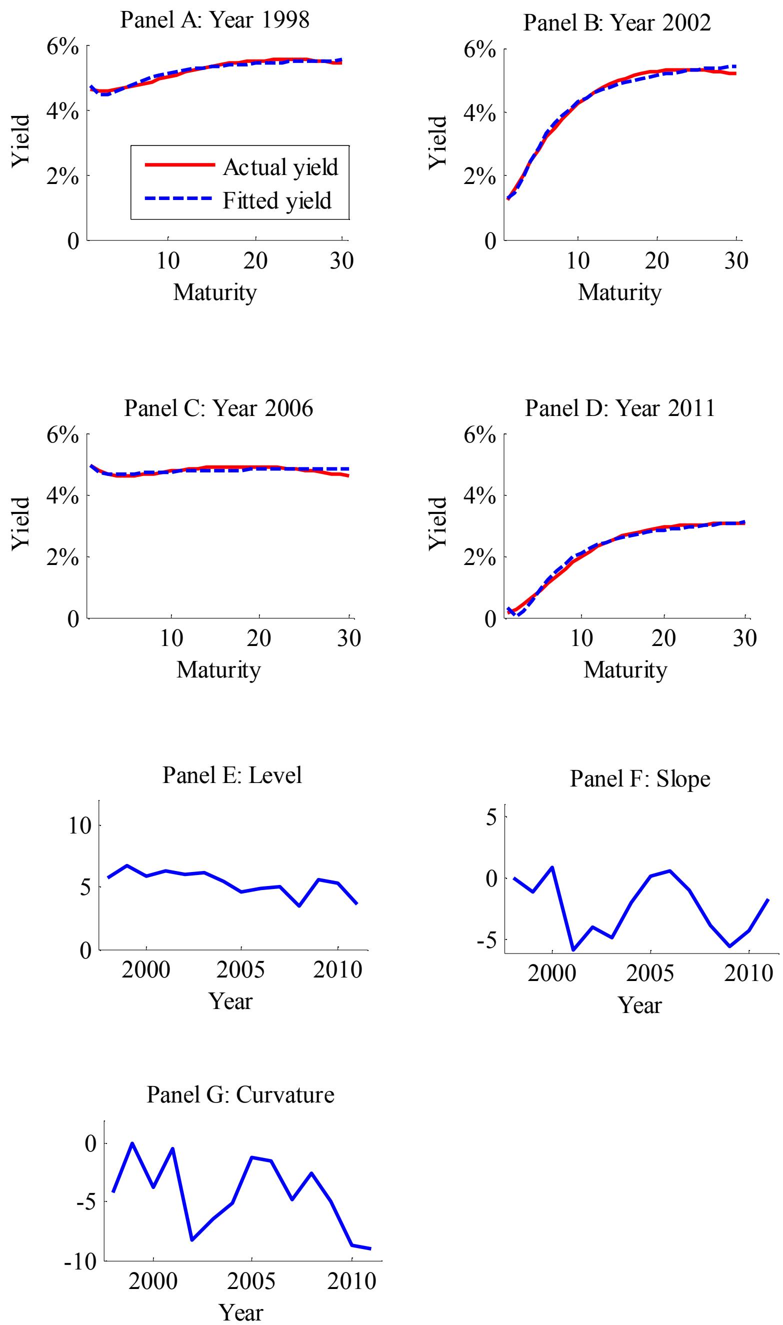


Figure 2: Aggregate Portfolio Durations and Term Structure Factors

This figure plots the time series of the level, slope and curvature durations (DURL, DURS, and DURC) of insurers' aggregate portfolios (separately for PC and life insurers) against the corresponding interest rate factors.

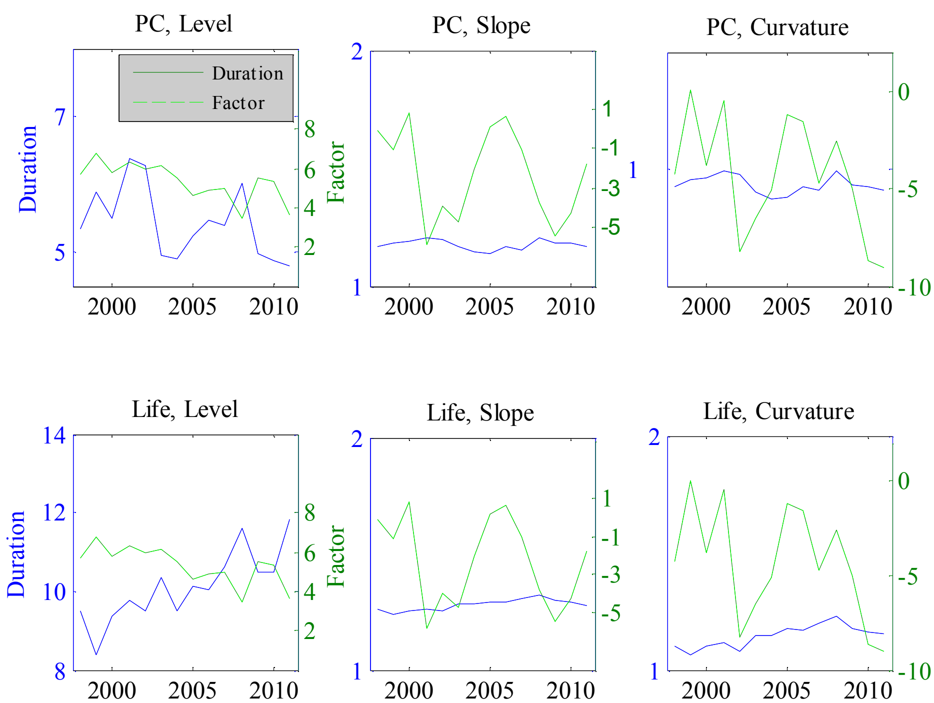


Figure 3: Aggregate Portfolio Weights

The figure plots insurers' aggregate portfolio weights (separately for PC and life insurers) in 11 maturity bins for four representative years: 1998, 2002, 2006, and 2011.

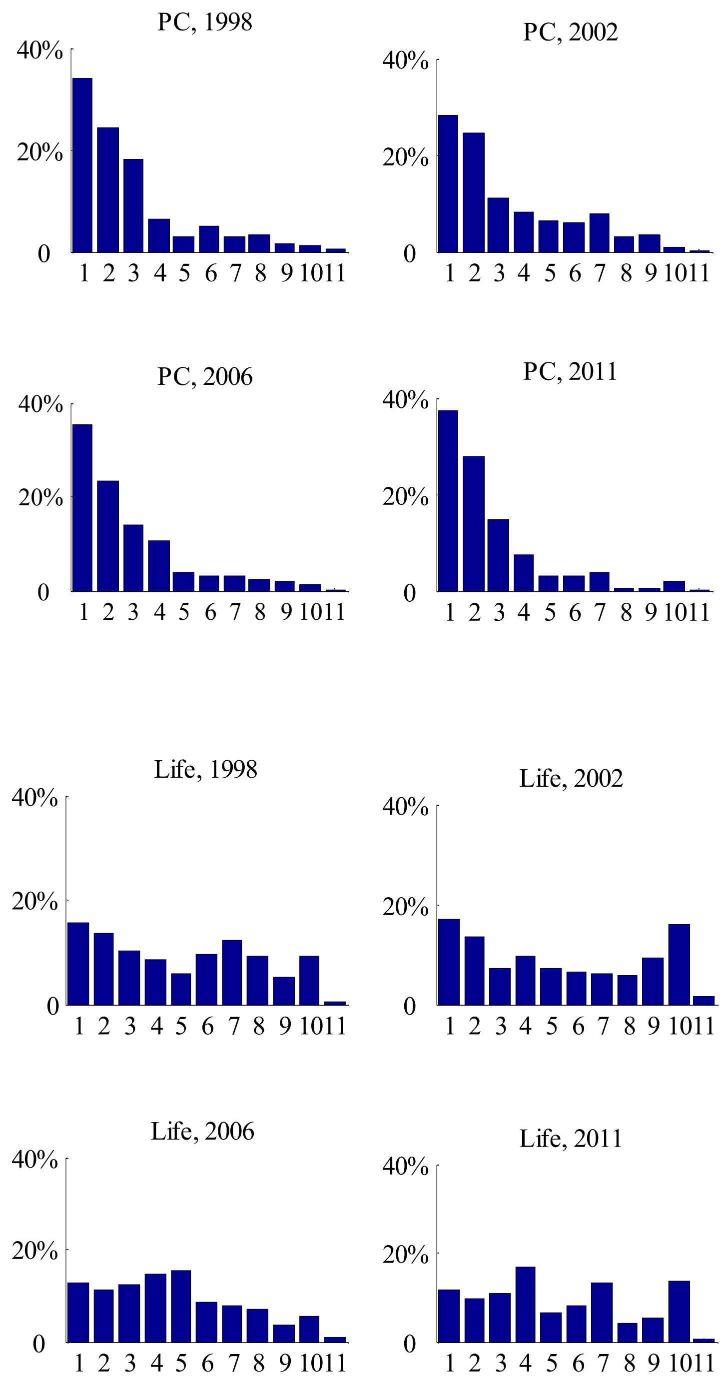


Figure 4: Elasticities of Aggregate Portfolio Weights to Interest Rate Factors

The figure plots the elasticities of portfolio weights of various maturity bins with respect to the interest rate factors. The elasticities are the coefficients of regressing the portfolio weights onto the three interest rate factors (level, slope, and curvature). Statistical significance at the 10%, 5%, and 1% level are indicated by *, **, and ***, respectively.

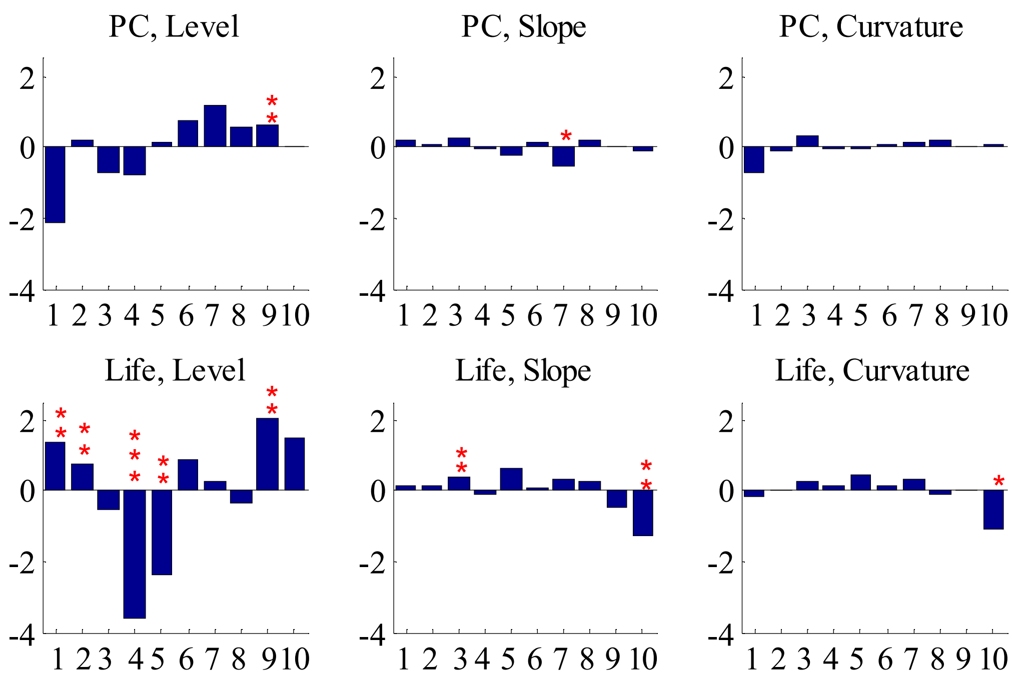
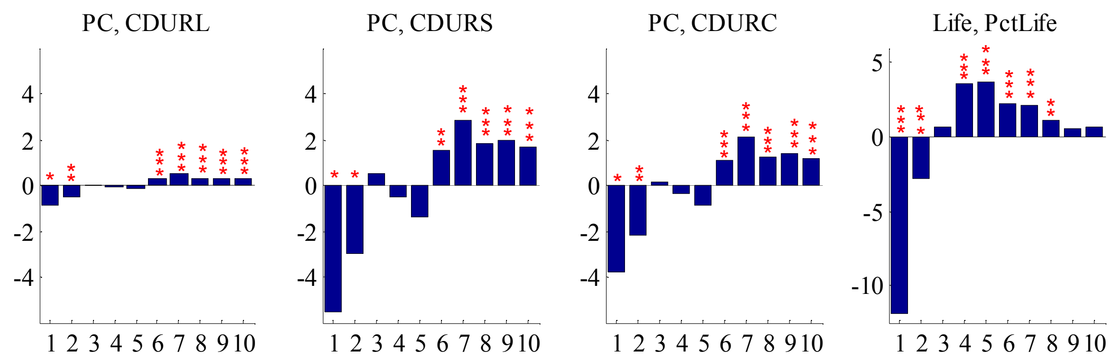


Figure 5: Effect of Liability and Risk Aversion on Portfolio Weights

The figure plots the coefficients of cross-sectional regressions that analyze the effect of liability and risk aversion on individual insurers' portfolio weights of various maturity bins. The dependent variable is the time-averaged portfolio weight of a given maturity bin for individual insurers. In Panel A, the explanatory variable is one of the liability duration proxies—CDURL, CDURS, and CDURC for PC insurers and PctLife for life insurers. In Panel B the explanatory variable is one of the four risk aversion proxies—INDEP, NODIV, YOUNG, and LOWCAP. The regressions are performed for PC insurers and life insurers separately. Statistical significance at the 10%, 5%, and 1% level are indicated by *, **, and ***, respectively.

Panel A



Panel B