By Force of Habitat? A First Look at Insurers' Government Bond Portfolios

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Abstract

The preferred habitat hypothesis links the shape of the term structure to inelastic demand in the bond market and is regarded as the theoretical underpinning of recent monetary policies. This study provides microeconomic level evidence of habitat in the portfolios of an important group of government bond investors – insurance firms. Using a simple dynamic portfolio model we highlight two forms of habitat that are due to two hedging components in an institutional investor's portfolio, one against the interest rate risk associated with liability and another against the interest rate risk associated with investment horizon. Empirically, we find that insurers' portfolio durations are strongly related to their liability characteristics, such as the ratio of claim-related liabilities to total investments and the durations of claim-related liabilities. Liability concerns also dampen portfolio response to term structure changes. However, the evidence on the investment horizon effect is mixed; and if any, insurers' investment horizon appears relatively short. These findings highlight the importance of institutional investors' liability structure in causing inelasticity of bond demand.

1 Introduction

The preferred habitat hypothesis is one of the earliest theories 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. Interest in this hypothesis has surged recently around the second "quantitative easing" (QE2) program of the Federal Reserve. A growing number of studies have used preferred habitat as a base to understand the impact of demand and supply shifts in the bond market and to evaluate monetary policies.[1]

While existing studies have demonstrated the usefulness of preferred habitat in macroeconomic analysis, so far there is surprisingly little evidence on issues that speak to the microeconomic foundation of the theory. These issues include, for example, what types of bond investors exhibit preferred habitat? How do we judge the importance of habitat in their portfolios? And what causes their inelastic demand for specific maturities? Perhaps due to data constraints, such questions have been left unanswered since the origin of the hypothesis.

Answers to these questions are central to assessing an oft-perceived conceptual drawback of the hypothesis – that is, it relies on somewhat arbitrary maturity preference or suboptimal behavior by investors, potentially resulting in arbitrage opportunities. Such an implication

[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. Greenwood, Hanson, and Stein (2010) present evidence that the maturity structure of corporate debt varies in a way that complements the maturity structure change of government bonds because firms behave as macro liquidity providers. 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 (2010, 2011) 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 that the Federal Reserve quantitative easing programs have a combined impact of 100 basis points on the ten-year Treasury yield.

is certainly at odds with the well-recognized efficiency of the government bond market. Recent theoretical work has made substantial progress to reconcile the preferred habitat effect with rational investment decisions. Vayanos and Vila (2009) incorporate the interaction between arbitrageurs and habitat investors into an arbitrage-free term structure model and demonstrate interesting properties of the resulting term structure. Further, theoretical studies such as Campbell and Viceira (2001), Watcher (2003), Liu (2007), and Detemple and Rindisbacher (2010), show that the habitat-like demand for bonds arises as risk-averse investors optimally hedge against the interest rate risk over their investment horizons or life cycles. Thus the macroeconomic phenomenon of preferred habitat can be potentially linked to individuals' rational life-time investment and consumption decisions. However, a hurdle exists when taking the theory to the data: the government bond market is dominated by institutional investors such as insurers, pensions, banks, and mutual funds, while individuals typically hold government bonds indirectly. Therefore, it is desirable to understand preferred habitat as part of institutional investors' portfolio decisions.

This study provides empirical analysis to address some of the key microeconomic-level questions raised above. Our analysis takes advantage of the comprehensive portfolio data for an important group of institutional investors in the government bond market – insurance firms. According to Federal Reserve Flow of Funds Accounts statistics in recent years, a few thousand insurers in the U.S. regularly invest about two-thirds of their assets in bonds, and one third of which are government bonds. Besides information about their insurance operations, insurers are required by regulation to report details of their investment portfolios each year. Such data are rarely available from any other type of bond investors.

We use a simple dynamic portfolio choice model to guide the analysis of preferred habitat from an institutional investor's perspective. The model incorporates two sources of habitat – investment horizon and liability. It is worth noting that institutional investors' liabilities could be ultimately traced to individuals' consumption and investment decisions – for example, the maturities of pension liabilities are related to employees' retirement horizons, and the maturities of claims under life insurance policies are determined by policyholders' life expectancies. Thus our model can be viewed as a practical reincarnation of existing habitat models based on individuals' life-cycle decisions. However, 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 demand directly from individuals.

In the model, preferred habitat shows up as two hedging components of the optimal portfolio. The first component can be intuitively expected but nonetheless important to derive in a dynamic portfolio problem – it completely immunizes the interest rate risk associated with liability. The second component hedges the interest risk associated with investment horizon. These two portfolio components are unresponsive to market conditions, and are referred to as the liability habitat and horizon habitat (named after their respective hedging purposes). Between the two, the liability effect is more prominent – an institution must first allocate part of the portfolio to fully immunize its liability, and the horizon habitat appears only in the *remaining* part of the portfolio. As a further distinction, while the horizon habitat increases with risk aversion, the liability habitat is independent of the degree of risk aversion and even exists under log utility.

We examine several implications of the model using the portfolio data of 2282 property and casualty (P&C) insurers and 781 life insurers, over a 12 year period from 1998 to 2009. In most part of the analysis the focus is on the durations of insurers' government bond portfolios, which summarize the portfolios' average cash flow maturities and interest rate risk exposures. The government bond portfolios of P&C insurers and life insurers exhibit several noted differences in duration characteristics and thus are analyzed separately. The average portfolio duration is 4.23 years for P&C insurers, and 5.77 years for life insurers. Portfolio durations vary modestly across insurers, with cross-sectional standard deviation of 2.23 years for P&C insurers and 3.30 years for life insurers. By contrast, the time variation of portfolio durations for any given insurer is quite low. The average time series standard deviation of portfolio duration for a typical P&C insurer is 1.20 years and that for a typical life insurer is 1.51 years. This is a telling sign of habitat.

Using a panel regression approach, we detect a significant liability habitat effect on insurers' portfolio durations. Liability habitat is proxied by the product of the ratio of claims-related liability to total investment and the estimated claim duration. The claim durations for P&C insurers are estimated directly using data from their mandatory filings. For life insurers, no comparable claims data are available, and we alternatively construct a proxy for claim duration using the proportion of total insurance premiums generated by life policies, based on the observation that life insurers typically also engage in other insurance business with substantially shorter claim durations (e.g., healthcare insurance). The analysis shows that the portfolio durations of both types of insurers exhibit a significantly positive relation with their respective liability habitat proxies. Further, we find that the regression's explanatory power mainly comes from the firm-specific but time-invariant components of the liability to investment ratio and claim duration proxies, while the time-varying components of these variables do not add much power. This suggests that for a typical insurer, the liability habitat is quite stable over time.

The evidence for the horizon habitat effect, however, is mixed. Our model suggests that if insurers have relatively long investment horizons, the observed portfolio durations should be positively related to insurers' risk aversion, and a high liability to investment ratio would dilute such a relation. We investigate this prediction using three proxies for risk aversion based on the difficulty of obtaining external financing – firm size, corporate form (stock vs. mutual), and affiliation with parent groups or holding companies.[2] Interestingly, among both P&C and life insurers, smaller firms and un-affiliated firms tend to have shorter portfolio durations, indicating a negative relation between portfolio duration and risk aversion.[3] Yet, mutual insurers tend to have longer portfolio durations than stock insurers, indicating a positive relation between portfolio duration and risk aversion. When we further take into account the influence of liability, the three risk aversion proxies continue to produce conflicting

[2]The choice of the risk aversion proxies follows the corporate risk management literature, which suggests that financing constraint is an important determinant of firms' risk aversion in investment and hedging decisions. Large insurers, stock insurers, and affiliated insurers tend to have easier access to external financing than small, mutual, and unaffiliated insurers.

[3]The negative relation of portfolio duration with risk aversion suggests that insurers' investment horizon is on average *shorter* than the duration of the non-habitat portfolio component. This could be due to an agency effect discussed later in the paper.

results and thus generate mixed evidence for the horizon habitat effect.

Finally, we examine how habitat affects insurers' portfolio response to term structure changes. In order to capture portfolio response to important forms of term structure shape changes, we use the estimated parameters of the Nelson-Siegel model to characterize the level, slope, and curvature factor of the term structure, and construct measures of portfolio sensitivity to these term structure factors. Based on such measures, we find that insurers' portfolios are sensitive to the changes in interest rate level and slope factors but insensitive to the curvature factor. Further, there is evidence of a liability effect on the portfolio response – insurers with higher liability to investment ratios tend to have more restrained portfolio response to the term structure factor changes. Finally, there is little evidence that risk aversion reduces portfolio response to term structure changes.

Overall, the findings of this study reveal the habitat behavior in insurers' government bond demand, thus providing microeconomic-level support to a key assumption of the preferred habitat theory. Between the two sources of habitat, we find relatively strong evidence for a liability channel, while the evidence for the horizon channel is weak. In addition, 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, including Greenwood and Vayamos (2010b), Krishnamurthy and Vissing-Jorgensen (2011), Hamilton and Wu (2012), Li and Wei (2012), among others. Our findings also have an interesting macroeconomic-level implication that is so far unexplored – the demand elasticity for government bonds at different maturities may be quite different, and in order to locate such demand inelasticity, institutional investors' liability structure deserves close attention.

In addition to the preferred habitat literature, our paper is also related to several recent studies that examine the investment strategies and performance of investors in the government bond market. For example, Ferson, Henry, and Kisgen (2006) evaluate the performance of government-bond mutual funds using a stochastic discount factor approach that addresses the interim trading bias in performance measurement. Huang and Wang (2010) and Moneta (2011) use the portfolio holdings of government-bond mutual funds to evaluate market timing and security selection aspects of fund performance.

The remaining of the paper is organized as follows. Section 2 introduces the dynamic portfolio choice model for institutions facing finite investment horizon and liability. Section 3 discusses the data. Section 4 reports the empirical results. Section 5 concludes.

2 A Tale of Two Habitats

To illustrate the intuition of the preferred habitat effect, we introduce a dynamic portfolio model for institutional investors in a stochastic interest rate environment. The model reveals two forms of preferred habitat. The horizon habitat arises because a risk averse institution prefers securities offering safe returns over its investment horizon. The liability habitat arises out of the institution's desire to hedge away interest rate risk associated with its liability.

2.1 Horizon Habitat

We first introduce a model with 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 zero-coupon bonds (or synthetic bonds) available for trading. These bonds do not have default risk, and are priced according to a general form of 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 full rank. After one bond matures it can be replaced by any other non-redundant bond. The market is not required to be complete.

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. Iterating over the budget constraint we have $W_H = W_t \Pi_{\tau=t+1}^{H} R_{p\tau}$. The value function of the above dynamic programming problem, or the indirect utility function J_t, can be expressed as:

$$J_t = E_t(J_{t+1}) = W_t^{1-\gamma} E_t \frac{\left(\Pi_{\tau=t+1}^{H} R_{p\tau}\right)^{1-\gamma}}{1-\gamma} \tag{2}$$

To illustrate the horizon habitat we provide an expression 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:

$$\omega_{\mathbf{t}} = \frac{1}{\gamma}\mathbf{\Omega}^{-1}(E_t \mathbf{r_{t+1}} - r_{ft+1}\iota + \frac{1}{2}\mathbf{V}) + \frac{\gamma-1}{\gamma}\mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, r_{ht+1}) + \frac{1-\gamma}{\gamma}\mathbf{\Omega}^{-1}\text{Cov}(\mathbf{r_{t+1}}, x_{t+1}) \tag{3}$$

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 the bond maturing at time H. $r_{p\tau}$ is the log portfolio return and $x_{t+1} = \sum_{\tau=t+2}^{H}(r_{p\tau} - r_{f\tau})$ summarizes the future portfolio "risk premium" – log portfolio return in excess of the log return to the maturity-H bond.

The optimal portfolio weight has three terms. The first term is a static mean-variance component. The other two terms are hedging components – the first hedging against the interest rate risk of the maturity-H bond, and the second hedging against future changes in "risk premium". Thus intuitively, they are the interest rate hedging component and the risk premium hedging component. The horizon habitat, or preference for the H-maturity bond, shows up in the second term, because the H-maturity bond is the perfect hedging instrument for the interest rate risk specified in this term.

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.[4] 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.

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) shows 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 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.

2.2 Liability Habitat

We now include the liability habitat. Suppose the investor faces a liability of amount L maturing on time K, with $1 < K \leq H$. For simplicity, assume that one of the available bonds matures at time K. The investor maximizes the same expected utility function as in

[4]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. Intuitively, 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.

(1), with the modified budget constraint:

$$\text{Max} E_0 (\frac{W_H^{1-\gamma}}{1-\gamma}) \tag{4}$$

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 show 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).

The details of the optimal portfolio are as follows. Let B_t be the time-t price of a zero-coupon bond that matures at time K and pays off \$1 at maturity. At time 0, invest the amount $B_0 L$ in this K-maturity bond. This position is held without rebalancing until time K, at which point the bond is sold to 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 remaining value of the time-t wealth, $W_t - LB_t$, is allocated to bond m according to the weight ω_{mt}, which is the optimal weight in the problem of (1). Let $\alpha_t = LB_t/W_t$. The weight for a bond in the entire portfolio is thus $\omega^*_{mt} = \alpha_t + (1-\alpha_t)\omega_{mt}$ for the K-maturity bond and $\omega^*_{mt} = (1-\alpha_t)\omega_{mt}$ for other bonds. After time K, 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.

Therefore, the liability habitat, or the hedging demand for the K-maturity bond, is due to the investor's desire to neutralize the liability interest rate risk. This form of hedging against the interest rate risk of liability is known as complete immunization or cash flow matching in the asset-liability management practice. In the static optimization setting, there is a question whether complete immunization or some less stringent form of hedging is better. We show that complete immunization is optimal in a dynamic portfolio choice problem. Intuitively, this is because immunization is costless measured by the marginal utility of the investor, which is in turn due to that even without liability, at the optimal the investor must already be indifferent between holding the K-maturity bond and holding any other bond.

It is further interesting to note that unlike that of the horizon habitat, the magnitude of the liability habitat is independent of the level of risk aversion as long as the investor is risk averse. Indeed, one can verify that the liability habitat exists even under the log utility, i.e., when $\gamma = 1$ (see further discussion in Appendix A.2). Therefore, even though the liability habitat can be viewed as ultimately resulting from individuals' investment horizon effect, its impact on the bond demand, hence the impact on the term structure of interest rates, may be quite different from that of the horizon habitat.

2.3 Implications for Portfolio Durations and Hypothesis Development

We use portfolio duration to summarizes the interest rate risk of a portfolio, which is also intuitively the weighted average of cash flow maturities of the bonds in the portfolio. The model in the previous section suggests that an investor's optimal portfolio duration, D_t^*, can be expressed in the following form:

$$D_t^* = \alpha_t K_t + (1 - \alpha_t)(w_{\gamma t} H_t + (1 - w_{\gamma t}) O_t) \tag{5}$$

where K_t is the liability duration, H_t is investment horizon (i.e., the duration of the portfolio component hedging against interest rate risk over the entire investment horizon), and O_t is the duration of the myopic portfolio component plus the component hedging against future risk premium changes – for convenience these two portfolio components will be jointly referred to as the "opportunistic component" (different from the "speculative component", which typically refers to the myopic component alone). Further, α_t is the ratio of liability to investment (total portfolio value), $w_{\gamma t}$ is the weight of the interest rate hedging component in the optimal portfolio without liability (c.f. Equation (3)). Thus, $\alpha_t K_t$ represents the liability habitat effect on portfolio duration and $(1 - \alpha_t) w_{\gamma t} H_t$ represents the horizon habitat effect. Note that the liability habitat effect $\alpha_t K_t$ is independent of risk preference, but $w_{\gamma t}$ in the horizon habitat increases with risk aversion.

Empirical analysis must be based on the observed (or measured) portfolio duration, instead of the unobserved optimal duration. The deviation of observed duration from the optimal duration can be due to various reasons, such as temporary money inflows and outflows, imperfect portfolio rebalancing, optimization errors, portfolio reporting errors, securities mispricing, and trading to take advantage of such mispricing, and behavioral biases, etc. To facilitate empirical analysis, we further assume that the observed duration is $D_t = D_t^* + \epsilon_t$. The deviation ϵ_t has zero mean, and is uncorrelated with D_t^*.

Although we have allowed all the variables in the optimal portfolio duration expression (5) to be time varying, some variables may be slower-moving than others. In particular, variables driving the habitat components of portfolio duration, α_t, K_t, $w_{\gamma t}$, and H_t are relatively stable firm characteristics. On the other hand, the component that responds to market conditions, O_t (as well as the temporary deviation ϵ_t), may be more volatile. In one variation of our analysis we assume that α_t, K_t, $w_{\gamma t}$, and H_t are all constants and the optimal portfolio duration takes the following form:

$$D_t^* = \alpha K + (1-\alpha) w_\gamma H + (1-\alpha)(1-w_\gamma) O_t \tag{6}$$

where α, K, w_γ and H are unconditional mean of α_t, K_t, $w_{\gamma t}$, and H_t. Thus the only time-varying component in the optimal duration is O_t. This model means that, in a panel setting, the liability habitat and horizon habitat are both part of the firm fixed effects.

We develop three testable hypotheses based on the portfolio duration implications of the model, one for each component of the portfolio duration. The first hypothesis is on the liability habitat.

(H1) *The portfolio duration is positively related to the liability habitat (i.e., $\alpha_t K_t$ in (5)).*

The second hypothesis is on the horizon habitat, which requires further discussion. The horizon habitat is determined by both investment horizon and risk aversion, and neither is directly observed. In empirical analysis we identify insurer characteristics related to risk aversion. But it is not straightforward to determine insurers' investment horizon. While it is straightforward to understand the investment horizon of an individual investor, the concept of investment horizon of a financial institution is more 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. Thus, insurers' effective investment horizons depend on the importance of the agency effect.

Without observing insurers' actual investment horizons or the magnitude of the agency effect, we opt to detect the presence of the horizon habitat via its relation with risk aversion. Recall that the liability habitat is independent of risk aversion while the horizon habitat effect increases with risk aversion; that is, w_γ increases to one as $\gamma \to \infty$.

A further complication is that w_γ interacts with both H_t and O_t in (5). As long as risk aversion is finite, if we detect a statistical relation between the portfolio duration and risk aversion, it is the joint effect of horizon habitat and the duration of the opportunistic portfolio component. In other words, the relation between the portfolio duration and risk aversion depends on whether the investment horizon is longer or shorter than the duration of the opportunistic portfolio component. Thus, we have,

(H2) *If the investment horizon is longer than the duration of the opportunistic portfolio component, then portfolio duration increases in risk aversion after controlling for the ratio of liability to portfolio value. If the investment horizon is shorter than the duration of the opportunistic portfolio component, then portfolio duration decreases in risk aversion.*

The third hypothesis has to do with the effect of preferred habitat on the sensitivity of portfolio to term structure changes. In the optimal portfolio, neither the horizon habitat nor the liability habitat depends on the shape of the term structure. Only the opportunistic component of the portfolio responds to term structure changes, and the magnitude of such response depends on the magnitude of the liability habitat and risk aversion.

(H3) *The portfolio sensitivity to term structure change decreases as the ratio of liability to investment increases, and decreases as risk aversion increases.*

Note that to examine the third hypothesis we have to go beyond the portfolio duration, which only measures the sensitivity of portfolio value to the level of interest rate. In Section 3.4 we introduce alternative measures that quantify how insurer portfolios respond to changes in three important characteristics of the term structure, i.e., the level, slope, and curvature.

3 Data

3.1 Data and Sample

Data used in the analysis are from several sources. The first is the Schedule D data from the National Association of Insurance Commissioners (NAIC). NAIC compiles annual regulatory filings by insurers on their securities holdings and trades in the form known as the "Schedule D". Reported securities include stocks, preferred stocks, and bonds. For bonds, 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.

For the government bond sample we start with all straight U.S. treasury bonds and agency bonds reported in the Schedule D data. These government bonds are further classified into two categories: 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) Single Class Mortgage-Backed/Asset-Backed Securities, which are pass-through certificates and other securitized loans issued by the United States government that are exempt pursuant to the determination of the Valuation of Securities Task Force. We only keep the issuer obligation type and exclude the mortgage/asset-based securities. Further, we exclude bonds with special characteristics such as bonds with credit enhancements, convertible bonds, Yankee, Canadian, foreign currency bonds, globally-offered bonds, redeemable, putable, callable, perpetual, or exchangeable bonds, and preferred securities. We also require the bonds to have non-missing coupon rate and positive face value. A few bonds with apparently incorrect CUSIPs are also removed.

Insurers hold other securities and instruments that are subject to interest rate risk, for example, corporate bonds, municipal bonds, mortgage backed securities, and interest rate derivatives. Quite possibly, insurers use these alternative instruments in addition to government bonds to manage their interest rate risk exposure. We focus on government bonds for the following reasons. First, our primary objective is to examine the inelastic demand for government bonds per se, rather than insurers' complete interest rate risk exposure. The inelasticity of government bond demand is an important issue from a monetary policy perspective. The Federal Reserve's second Large Asset Purchase Program (i.e., QE2) 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. 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 correlation with the interest rate will necessarily introduce a substantial amount of further complexity.

The second dataset used in this study is INFOPRO, also from NAIC. INFOPRO provides insurers' financial statements (different from the typical financial statements in Compustat) as well as their demographic information. From the INFOPRO data we select all property and casualty insurance companies and life insurance companies. 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. In addition, 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.

As detailed later, we also use the NAIC Schedule P data to measure P&C insurers' claims durations. The annual Schedule P filings by P&C insurers report the claims received and paid during the past ten years.

The sample period is from 1998 to 2009. Table 1 reports the summary statistics on asset characteristics of insurers in the sample. As Panel A of the table shows, there are 2,282 unique P&C insurers in the sample, with annual numbers varying between 1160 (in 2001) and 1312 (in 1998). Their average total assets increase over time, from $620 million in 1998 to $1,102 million in 2009. The table further reports the following asset items as fractions of total assets: i) invested assets, ii) value of bond and stock holdings, iii) value of bond holding, iv) value of government bond holdings as reported in the summary page of Schedule D, and v) value of government bond holdings included in our sample. For P&C insurers, invested assets account for 85% of total assets, with the majority investments in stocks and bonds (73% of total assets), and prominently in bonds (62% of the total assets). Based on the summary data for Schedule D, 22% of total assets are government bond holdings. The number is slightly lower based on the government bond holdings included in our sample (20%) due to the sample selection criteria.

Panel B of Table 1 shows that there are 781 unique life insurers in the sample. Life insurers are much larger, with average total assets of $6,214 million. Relative to P&Cs, life insurers have more invested assets (94% of total assets) and invest more in bonds (70% of total assets). Interestingly, the fraction of government bond holdings is lower for life insurers than for P&Cs (16% vs 22%).

Table 2 reports the unique numbers of government bonds held by insurers. In total, P&C insurers hold 20,653 unique government bonds while life insurers hold 11,100 unique government bonds during the entire sample period. Among the government bonds held by each type of insurers, there are many more agency bonds than Treasury bonds. These bonds have varying maturities. P&C insurers hold a high number of bonds with maturity between 3 and 10 years, while life insurers hold a high number of bonds with medium maturity (3 to 10 years) and long maturity (beyond 10 years).

3.2 Portfolio Duration

The Macaulay duration $\mathrm{DUR}_{j,t}$ for an individual coupon bond j at time t is calculated as:

$$\mathrm{DUR}_{j,t} = \frac{\sum_{n=1}^{N} \frac{\mathrm{nC}_n}{(1+r)^n}}{\mathrm{P}_{j,t}}, \tag{7}$$

where N is the total number of remaining periods, C_n is the n-th period cash flow (coupon plus principal payment), r is the bond's yield to maturity at time t, $\mathrm{P}_{j,t}$ is market price of the bond at time t. The data for calculating bond durations are from Schedule D.

The duration of a portfolio is the weighted average of the durations of all government bonds held in the portfolio:

$$\mathrm{D}_t = \sum_{j=1}^{M} \mathrm{w}_{j,t}\mathrm{DUR}_{j,t} \tag{8}$$

where $\mathrm{DUR}_{j,t}$ is the Macauly duration of bond j at time t. M is the number of bonds held in the portfolio. $\mathrm{w}_{j,t}$ is the time-t weight of bond j in the portfolio. In order to obtain reliable estimates of portfolio duration, we require an insurer to hold at least 10 bonds in year t for that insurer-year observation to be included in our analysis.

The last column of Table 1 provides the average portfolio durations of P&C and life insurers in each sample year. On average, the portfolio duration of P&C insurers is 4.23 year and that for life insurers is 5.77 years.[5] Life policies have longer maturities and claims on life policies can take place over a very long period of time. This might explain the difference in portfolio durations between the two types of insurers. However, an average portfolio duration of 5.77 years appears to be short, relative to the commonly perceived long claim durations for life insurance policies.

There are several possible factors to account for the difference between the perception and data. First, as mentioned earlier, life insurers often engage in other forms of insurance

[5]The average portfolio duration of life insurers is quite close to the duration of the aggregate Barclays Capital U.S. Government Bond index. We thank Pierluigi Balduzzi and Alan Marcus for pointing out this. A possible explanation is that life insurers passively manage a large part of their government bond portfolios to minimize tracking errors with respect to this major index. This would further suggest that they do not have strong liability concerns. However, some empirical evidence reported later suggests that insurers do not simply follow a passive indexing strategy.

that have much shorter durations for insurance claims, such as accidental insurance and healthcare insurance. Second, among various types of life policies, term-life policies have shorter durations relative to whole-life policies. Thus the overall life insurance claim duration depends on the mix of term-life vs. whole-life policies. Third, while the typical duration of life insurance claim is long, so is the duration for the future insurance premiums expected under a policy. Thus the net duration of the policy, after taking into account the future insurance premiums, is effectively shortened.[6] Finally, as mentioned earlier, it is possible that insurers use other long-duration assets, such as corporate bonds and derivatives to hedge part of the liability interest rate risk.

3.3 Insurer Characteristics

To test the hypotheses developed in Section 2.3 we will make use of two types of insurer characteristics – variables related to insurers' liabilities and variables related to risk aversion.

First, we construct a variable that measures the ratio of liability to total investment value, LTV, which serves as a proxy for α_t in the optimal portfolio duration expression (5). Although insurers have both financial liabilities as well operating liabilities, their financial liabilities typically are small relative to their operating liabilities arising from insurance claims. To construct LTV, we focus on their claim-related liabilities, obtained from insurers' financial statements titled "Liabilities, Surplus, and Other Funds" (from the INFOPRO data). For P&C insurers, we define claim liabilities to be the following data items: 1) Losses, 2) Reinsurance payable on paid losses and loss adjustment expenses, and 3) Loss adjustment expenses. For life insurers, claim liabilities are defined on the following items: 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 LTV, i.e.,

[6]For example, consider a whole-life insurance policy with a 20-year life expectancy. The expected claim duration is then 20 years. If premiums are collected annually over the 20-year span, at a 8% discount rate the duration of the expected premiums is 8.04 years. If the present value of future premiums is equal to the present value of claim payment, then the net duration of the policy (combining claim payment and premium collections) is 11.94 years. If the present value of the expected premiums is twice the present value of the expected claim payment, then the net duration of the whole-life policy is only 20-8.04*2=3.94 years.

total investment value, is the data item "Invested Assets" from their financial statements. In most part of the paper, our analysis will use the cross-sectional decile rank (for P&C and life insurers separately) of LTV, which is referred to as RLTV.

Second, we construct proxies for the duration of insurers' claim-related liabilities. For P&C insurers, we estimate the claim duration, ClaimDur, as the weighted average maturities of expected claim payments. The data are from insurers' Schedule P filing with NAIC. Appendix B provides details of the estimation procedure.

Life insurers are not required to disclose claim information similar to that provided in the Schedule P filings by P&C insurers. However, life insurers often engage in other types of insurance underwriting, such as accidental and healthcare insurance. These alternative types of insurance tend to have much shorter claim durations. Based on this observation, we construct a variable PctLife as a proxy for life insurers' claim duration. PctLife is the percentage of life insurance premiums in total premiums collected.

Based on the above, P&C insurers' liability habitat is proxied by LTV∗ClaimDur, while life insurers' liability habitat is proxied by LTV∗PctLife.

Next, we introduce proxies for insurers' risk preference. Unlike that for individuals, so far little is known about the risk preference of financial intermediaries such as insurers. Our proxies for insurers' risk aversion are motivated by the economic theory of corporate risk management. As pointed out by Froot, Scharfstein, and Stein (1993) and many other studies, a prominent reason for firms to engage in financial hedging and risk management is the existence of convex external financing cost or financing constraints.[7] We conjecture that firms with higher external financing costs will also act more averse to their investment portfolio risk.

Based on the above consideration, we construct the following three proxies for an insurer's risk aversion:

- SMALL: the annual cross-sectional decile rank of the inverse of total assets, for P&C

[7] There are other reasons provided in the literature for corporate hedging and risk management, such as managerial risk aversion (Stulz 1984), taxes (Smith and Stulz 1985), and cost of financial distress (Smith and Stulz 1985).

and life insurers separately. Small firms typically face stronger financing constraints and have higher external financing cost, hence may have higher institutional risk aversion.

- MUTUAL: a dummy variable taking the value of one if an insurer is a mutual company, and zero otherwise (e.g., for a stock company). Stock companies tend to have easier access to the capital market than mutual insurers.
- INDEPENDENT: a dummy variable taking the value of one if an insurer is not affiliated with any parent group or holding company, and zero otherwise. Parent groups and holding companies can reduce external financing costs of subsidiaries and provide additional risk sharing across subsidiaries. Non-affiliated insurers do not enjoy such benefit.

Table 3 provides summary statistics on the insurer characteristics. For P&C insurers, the average liability to investment ratio LTV is 38%. The average length of the claim duration ClaimDur is 2.1 years. 29% of P&C insurers are mutual firms and roughly one-third are not affiliated with a parent group or holding company. LTV of life insurers is much higher, at 65%. Life insurers have a bit more than half of business in the life insurance sector (57%), with the rest in health and annuity business. 12% of life insurers are mutual companies and 34% are independent firms.

3.4 Term Structure Factors and Nelson-Siegel Durations

The test of Hypothesis 3 outlined in Section (2.3) requires a practical and concise way to characterize the term structure of interest rates. For this purpose we resort to the Nelson and Siegel (1987) model, which characterizes the term structure of zero-coupon yields by a parsimonious polynomial-exponential function. Specifically, we use the Diebold and Li (2006) version of the model:

$$y_t(n) = \beta_{0t} + \beta_{1t}\frac{1 - e^{-n/\lambda_t}}{n/\lambda_t} + \beta_{2t}\left(\frac{1 - e^{-n/\lambda_t}}{n/\lambda_t} - e^{-n/\lambda_t}\right) \tag{9}$$

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. Diebold and Li (2006) show that the three parameters β_{0t}, β_{1t}, and β_{2t} intuitively can be related to the level, (inverse of) slope, and curvature of the term structure. They also show that these three factors have very high correlations with the first three principal component factors of the term structure; e.g., Litterman and Scheinkman (1991). For this reason we simply refer to β_{0t}, β_{1t}, and β_{2t} as the level, slope, and curvature factors. In addition, the location of the curvature top is determined by the parameters λ_t.

When estimating the model (9), 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 the parameters β_{0t}, β_{1t}, and β_{2t} using OLS. The zero-coupon yields $y(n)_t$ used in estimation are for the 30 consecutive maturities from 1 to 30 years. We run the regression during each sample year using the year-end yields. The yield data are obtained from Gürkaynak, Sack, and Wright (2007), who combine US Treasury bond price data from CRSP and Federal Reserve Bank of New York to construct by far the most complete daily time series of the zero-coupon yields at maturities ranging from 1 to 30 years. Their data are updated and made available at a Federal Reserve Board website.[8]

Another advantage of using the Nelson-Siegel model is that the sensitivities (i.e, partial derivatives) of bond value and portfolio value to the three term structure factors β_{0t}, β_{1t}, and β_{2t} have close-form expressions and can be easily computed. Based on these expressions one can further derive sensitivity measures of portfolio value to term structure factors, in a way similar to the conventional notion of bond duration. The generalized portfolio duration

[8]http://www.federalreserve.gov/pubs/feds/2006/200628/feds200628.xls. Gürkaynak, Sack, and Wright (2007) fit the Nelson-Siegel-Svensson model, which allows for a second hump in the yield curve. Theoretically it is feasible to examine insurers' portfolio response to all the four term structure factors under the Nelson-Siegel-Svensson model, i.e., level, slope, and two curvature factors. However, as they note, the time series of the factors (especially the two curvature factors) estimated from the Nelson-Siegel-Svensson model are somewhat unstable. In addition, we find that the correlation between the estimated level factor and the slope factor, and the correlation between the two curvature factors, are highly negative. This may confound the inference on portfolio response to individual factors. For this reason, we choose to perform analysis on the three term structure factors under the Nelson-Siegel model. We find that the OLS estimates of the three Nelson-Siegel factors are stable over time, and exhibit only modest correlations.

measures under the Nelson-Siegel model are derived in Willner (1996) and Diebold, Ji, and Li (2006). They are referred to as the NS durations, and more specifically, the level duration, slope duration, and curvature duration respectively. To derive these durations, note that the price of a bond can be expressed as:

$$P_t = \sum_{i=1}^{N} C_i e^{-n_i y_t(n_i)} \tag{10}$$

where N is the number of payments remaining for the bond. C_i is the i-th remaining payment (coupon and principal combined) of the bond. 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 four NS durations for the bond are defined as:

$$\text{DUR}_t^L = \frac{\partial P_t/P_t}{\partial \beta_{0t}} = -\sum_{i=1}^{N} v_{it} n_i \tag{11}$$

$$\text{DUR}_t^S = \frac{\partial P_t/P_t}{\partial \beta_{1t}} = -\sum_{i=1}^{N} v_{it} \lambda_t (1 - e^{-n_i/\lambda_t}) \tag{12}$$

$$\text{DUR}_t^C = \frac{\partial P_t/P_t}{\partial \beta_{2t}} = -\sum_{i=1}^{N} v_{it} \left[\lambda_t (1 - e^{-n_i/\lambda_t}) - n_i e^{-n_i/\lambda_t}\right] \tag{13}$$

Note that by construction, the level duration DUR^L is close to the *negative* of the conventional Macaulay duration except for a minor difference – the discount rate in the Macaulay duration is the yield to maturity while the discount rates for DUR^L (used in calculating v_{it} are zero-coupon yields.

The NS durations for a bond portfolio, D^L, D^S, and D^C, are the weighted averages of the NS durations of the bonds held in the portfolio. For example, the level duration for a portfolio is:

$$D_t^L = \sum_{j=1}^{M} w_{j,t} \text{DUR}_{j,t}^L \tag{14}$$

where $w_{j,t}$ is the portfolio weight on bond j (value of bond holding divided by total government bond portfolio value). A portfolio's slope duration D_t^S and curvature duration D_t^C are similarly defined.

4 Empirical Results

4.1 Cross-firm and Within-firm Variations of Portfolio Durations

To get a sense of the habitat-like behavior in insurer's portfolio duration, we first look at the variation of portfolio durations in the cross-section and in the time series.

Table 4 reports three measures of the sample variation of portfolio duration, separately for P&C and life insurers. The first, pooled variation, is the standard deviation of portfolio durations over all firm-year observations. It is 2.24 (year) for P&C insurers and 3.31 (year) for life insurers. The second, cross-firm variation, is calculated as the time series mean of annual cross-firm standard deviation over the 12 sample years. It is 2.23 (year) for P&C insurers and 3.30 (year) for life insurers, approximately the same as the pooled variation. To obtain the third measure, within-firm variation, we first calculate the standard deviation of portfolio duration for each insurer using all its time series observations, and then average across insurers. It is 1.20 (year) for P&C insurers and 1.51 (year) for life insurers. Relative to the pooled variation and cross-firm variation, within-firm variation is much smaller. In other words, while insurers may differ from each other in choosing portfolio durations, the duration of each insurer tends to stay within a close range over time, a telling sign of habitat.

4.2 Evidence on Liability Habitat

We use a panel regression approach to investigate the first hypothesis, i.e., the liability habitat effect. The dependent variable is the firm-year observations of portfolio duration. The explanatory variables are insurers' liability characteristics. The error term is assumed to be stationary but dependent across firms and over time. Essentially, we perform pooled OLS regression to obtain the coefficient estimates, while the standard errors are computed using a two-way clustering procedure, by firm and by year (see, e.g., Petersen 2009). Year dummies are included to control for unobservable heteroscedasticity along the time dimension. We do not control for firm fixed effects here; as we shall see later, the liability habitat effect is essentially part of the firm fixed effects.

As mentioned earlier, in most empirical analysis we use a rank-transformed liability to investment ratio LTV, RLTV. RLTV is the cross-sectional decile rank of LTV, in each year and for P&C and life insurers separately.[9] For P&C insurer, the proxy for liability habitat is RLTV times the claim duration estimate (ClaimDur). For life insurers, the corresponding proxy is RLTV times the percentage of total premiums collected from life insurance policies (PctLife). The results reported in the second and third columns of Table 5 show that for both types of insurers, there is a significant positive relation between the portfolio duration and their respective liability habitat proxies.

The liability habitat depends on both the ratio of liability to investment and measures of claims duration. In the remaining columns of the table we further investigate the effects of the two quantities separately. Columns 4 and 5 show that there is a significantly positive relation between portfolio duration and proxies for claims duration. For P&C insurers, one additional year of the claims duration (ClaimDur) increases the portfolio duration by 0.16 year. For life insurers, one additional percentage point in premiums collected by life policies (PctLife) increases portfolio duration by 0.0183 year (0.22 month). A comparison of the coefficients in Columns 4 and 5 with those in Columns 2 and 3 shows that most of the liability habitat effect is driven by the claim duration effect.

The last two columns report the sensitivity of portfolio duration to the decile rank of the liability to investment ratio, RLTV. The interpretation of the estimated coefficient for RLTV requires an additional explanation. From the portfolio duration expression (5), we see that RLTV (as proxy for α_t) interacts with both the liability duration and the duration of other components of the portfolio. To be exact, the coefficient on RLTV is affected by the difference between the liability duration and a weighted average duration of the horizon component and the opportunistic component. A positive coefficient for RLTV suggests that the liability duration is longer than the weighted average of the durations of the other components. This turns out to be the case in the data – the coefficient for RLTV is 0.05 for P&C insurers and

[9] We use RLTV instead of LTV, mainly because RLTV's interaction terms with other variables, especially with term structure factor changes (detailed later), have better distributional properties than the interaction terms involving LTV. However, all the key results remain essentially similar when we use LTV in the analysis. The same applies to the use of the decile rank of inverse firm size, SMALL.

0.32 for life insurers, both significantly positive.

Overall, the evidence is indicative of the existence of liability habitat.

4.3 Evidence on Horizon Habitat

As noted in Section 2.3, the examination of the horizon habitat is complicated by a few factors and we choose to focus on the relation between portfolio duration and insurers' risk preference. Further, the observed relation between portfolio duration and risk aversion depends on the liability to investment ratio, and the difference between investment horizon and the duration of the opportunistic component. This is the second hypothesis, which we examine here.

We continue to use the panel regression approach, with year fixed effects and two-way clustered standard errors for statistical inference. The dependent variable is the portfolio duration. In Panel A of Table 6, the explanatory variable is each of the three risk aversion proxies (RA) defined earlier – the inverse decile rank of firm size (SMALL), a dummy for mutual insurers (MUTUAL), and a dummy for non-affiliated insurers (INDEPENDENT). The results are consistent when SMALL and INDEPENDENT are used as the risk aversion proxies – smaller firms and independent insurers tend to have shorter portfolio duration. Recall that the relation between portfolio duration and risk aversion depends on the relative length of investment horizon and the duration of the opportunistic part of the portfolio. A negative correlation between risk aversion and portfolio duration indicates that insurers' investment horizons tend to be shorter than the durations of their opportunistic portfolio components. On the other hand, we also find that mutual insurers tend to have longer portfolio duration. This result is to the opposite of those based on SMALL or INDEPENDENT despite that they are all proxies for risk aversion. Thus, the evidence is mixed.

The expression (5) also suggests that risk aversion should affect portfolio duration jointly with the liability to investment ratio. To investigate this joint effect, we include RLTV, a risk aversion proxy RA, and the interaction term RLTV*RA as joint explanatory variables. The results are reported in Panel B of Table 6.

The estimated coefficients on RA in this panel are close to those in Panel A, and thus offering similarly mixed evidence. They are significantly negative for SMALL and INDEPENDENT and insignificant for MUTUAL. Further, the coefficients on the interaction between RLTV and RA are insignificant except for one case – it is positive with marginal significance for INDEPENDENT in the life insurer sample, but as such its sign is the opposite to the prediction. Thus, the inclusion of liability characteristics does not anywhere strengthen the case for the horizon habitat.

4.4 Cross-firm and Within-firm Variations of Habitat Effects

So far in the regression analysis of Section 4.2 and 4.3, we have used time-varying insurer characteristics as explanatory variables. In the panel setting, the effect of the time-variation of an explanatory variable within a firm is referred to as the *within-effect* while that of the time-invariant component of an explanatory variable across firms is referred to as the *between-effect*. Conceptually, insurers' liability structure, investment horizon, and risk aversion are relatively stable, and the time varying components of these variables may have large measurement error components that do not bear significantly on insurers' portfolio decisions. Translated into the panel terminology, this means that the habitat effect could show up strongly as the between-effect and weakly or non-existent as the within-effect. This is described in the conjecture of (6).

We investigate the within-effect and between-effect of the liability habitat and horizon habitat using the standard regression approaches designed to capture these two effects. To quantify the within-effect, we replace the dependent and explanatory variables in Table 5 and 6 with their de-meaned counterparts. Specifically, in the regressions for the liability habitat, we de-mean portfolio duration, the liability to investment ratio LTV (instead of the decile rank RLTV), ClaimDur, PctLife, as well as the interaction terms LTV*ClaimDur and LTV*PctLife by subtracting their corresponding insurer-specific means. In the regressions for the horizon habitat, since MUTUAL and INDEPENDENT are mostly largely time-invariant, we only include the de-meaned values of the log total assets lnASSET (instead of the decile rank SMALL) and LTV*lnASSET. We continue to include the year dummies in the panel regressions and use insurer and year double-clustered standard errors to compute t-statistics. To quantify the between-effect, we perform cross-sectional regressions. The dependent variable is the mean of portfolio duration for each insurer. The explanatory variables are the insurer-specific means of LTV, ClaimDur, PctLife, LTV*ClaimDur, LTV*PctLife, lnASSET, and LTV*lnASSET. The t-statistics are computed using the White (1981) heteroscedasticity-robust standard errors.

The results reported in Panel A of Table 7 show that there is no within-effect in the P&C sample for either the liability habitat effect or the horizon habitat effect. The coefficients for the de-meaned LTV, ClaimDur, LTV*ClaimDur, lnASSET, and LTV*lnASSET are all insignificant. On the other hand, there is some evidence of the within-effect for life insurers. In the liability habitat regressions, the coefficients for the de-meaned LTV and PctLife are highly significant, while that for de-meaned LTV*PctLife is marginally significant. In the horizon habitat regressions, the coefficient for lnASSET is significantly positive, while those for LTV and LTV*lnASSET are insignificant.

The results for between-effect regressions are reported in Panel B of Table 7. In the liability habitat regressions, the between-effect is very strong. For the P&C sample, while there is no significant within-effect (Panel A), all the between-effect regressions for the liability habitat yield significant results. For the life sample, although there is some evidence for the within-effect, the magnitude of coefficients and the t-statistics are much stronger in the between-effect regressions. In the horizon habitat regressions, the evidence is mixed. The coefficient for the mean of lnASSET is significantly positive. However the coefficients for the mean of LTV and the mean of LTV*lnASSET are insignificant.

The results from this part of the analysis largely confirm our initial conjecture that the time-invariant part of insurer characteristics plays the most critical role in explaining portfolio durations.

4.5 Portfolio Response to Term Structure Changes

So far our analysis has focused on patterns in insurers' portfolio durations. There is also a keen interest in learning how their portfolios respond to important shifts of market conditions. For example, when the yield curve flattens (as it did during the recent quantitative easing episodes), how do insurers adjust their government bond portfolio weights at various maturities, and how do liability habitat and horizon habitat affect such responses? These questions are apparently interesting from macroeconomic and monetary policy perspectives. They are formulated into Hypothesis 3 (see Section 2.3). To answer such questions, however, we must look at properties of bond portfolios beyond portfolio duration, because portfolio weight changes in response to market conditions such as flattening yield curve or increasing curvature cannot be fully characterized by the change of the conventionally-defined portfolio duration. For this purpose, in Section 3.4 we introduce four Nelson-Siegel (NS) portfolio durations D_t^L, D_t^S, and D_t^C, which quantify a portfolio's exposure to the level, slope, and curvature factors of the yield curve respectively.

To provide a more concrete intuition on Hypothesis 3, first note that based on the solution to the optimal portfolio described in Section 2.2, the NS durations of a bond portfolio are weighted average NS durations of the habitat and opportunistic components. Due to the similarity between the interest rate level duration D_t^L and the Macaulay duration, D_t^L takes the same form of the conventional portfolio duration described in (5) (except for a negative sign). Further, a portfolio's slope duration D_t^S and curvature duration D_t^C can be expressed as:

$$D_t^S = \alpha_t D_{K,t}^S + (1-\alpha_t) w_{\gamma t} D_{H,t}^S + (1-\alpha_t)(1-w_{\gamma t}) D_{O,t}^S$$
$$D_t^C = \alpha_t D_{K,t}^C + (1-\alpha_t) w_{\gamma t} D_{H,t}^C + (1-\alpha_t)(1-w_{\gamma t}) D_{O,t}^C$$

where $D_{K,t}^S$, $D_{H,t}^S$ and $D_{O,t}^S$ ($D_{K,t}^C$, $D_{H,t}^C$ and $D_{O,t}^C$) are the slope (curvature) durations of the liability habitat component, horizon habitat component, and opportunistic component of the portfolio, respectively. Hypothesis 3 is formed under the assumption that the NS durations of the liability habitat and horizon habitat components are less sensitive to the market conditions characterized by the changes in the three term structure factors, than the NS durations of the opportunistic portfolio component. Further, through the effect of $(1-\alpha_t)(1-w_{\gamma t})$ in the above expressions, the existence of liability habitat and horizon habitat reduces the weight of the opportunistic component, and thus reduces the overall sensitivity of the portfolio NS durations to the factor changes.

To test this hypothesis we perform the following panel regressions. The dependent variable is the change of one of the three NS portfolio duration measures, denoted as ΔD_t^L, ΔD_t^S and ΔD_t^C. The explanatory variables include the change in the corresponding term structure factor ΔF_t (denoted as ΔLevel, ΔSlope, and ΔCurv, respectively), as well as the liability to investment ratio rank (RLTV), the risk aversion proxies (RA), and their interaction terms with ΔF_t. The portfolio duration change and the term structure factor change ΔF_t are measured contemporaneously over the same one-year period.

Before reporting the empirical results, a few discussions on the regression design are in order. First, although the regressions measure the contemporaneous responses of insurers' portfolios to the term structure factor changes over a one-year period, the measured responses could well capture predictive moves of a portfolio to forward-looking information about term structure changes in a relatively short time window (e.g, monthly), or portfolio reaction to factor changes occurred in the recent past. If insurers' portfolios indeed respond to conditional information in the market that is predictive of the yield curve, their NS durations would move contemporaneously or predictively in relation to the term structure factor changes.[10] On the other hand, the reactive moves of NS durations to past factor changes are not the direct implications of optimal portfolio decisions, unless the factor changes that the portfolios respond to are predictive of future term structure changes or expected bond returns. Therefore, our annual contemporaneous regression approach represents a noisy measure of the habitat effect on the predictive portfolio response to market conditions. Interestingly, Diebold and Li (2006) show that the yield curve is predictable by lagged term

[10] Huang and Wang (2010) find that government bond mutual funds use information contained in macroeconomic variables to adjust portfolio durations ahead of interest rate level changes. Therefore, conditional information predictive of yield curve changes does exist.

structure factors, especially at 6-month and 12-month horizons. Thus investors may validly include past factor changes in their conditional information set to predict future term structure changes.

Second, because the NS durations are defined as the sensitivities of portfolio value to the factors, if an insurer has predictive information about the term structure change and adjust its portfolio accordingly, we would expect its NS portfolio duration changes to be positively related to the term structure factor changes. This is akin to the idea of market timing; that is, investors increase a portfolio's market beta in anticipation of positive market returns. Further, the effect of liability and risk aversion is to reduce such a positive response. Finally, portfolio weight changes include both an active component and a passive component. The former is due to active bond trading by insurers, and the latter is caused by price changes or interest rate changes on bonds held by insurers.[11] Accordingly, portfolio response to term structure change can have both active and passive components. It would be interesting to see to what extent insurers' portfolio duration management is achieved via active trading. However, ultimately, an insurers' objective is to adjust its portfolio durations toward optimal levels utilizing *both* the active and passive components of duration changes. For this reason and together with a concern for the quality and consistency of the bond trading data, we do not further differentiate the active NS duration changes from the passive changes.

To set a benchmark for comparison, we first analyze the portfolio response to term structure factor change without conditioning on the habitat effect. This amounts to univariate regressions of NS duration changes onto factor changes. The results are reported in Panel A of Table 8. As indicated by the regression coefficients and their t-statistics, for both P&C and life insurers, their portfolios have significantly positive response to the interest rate level factor. Portfolio responses to the slope factor are also significantly positive, although at a lower magnitude relative compared with the response to the level factor. However, portfolio responses to the curvature factor are insignificant.

[11]The passive portfolio NS duration changes can be from two sources. First, as bond prices change, the portfolio weights change. Second, similar to the effect of bond convexity, the NS durations of a bond change with interest rates.

Panel B of Table 8 further reports the effect of liability on portfolio responses. Here, the dependent variable continues to be the change of one of the three NS portfolio durations. The explanatory variables include, in addition to the corresponding factor change, the decile rank of liability to investment ratio RLTV, and the interaction term between RLTV and the factor change. The coefficients for the term structure factor changes are similar to those reported in Panel A. Further, for both P&C and life insurers, the coefficients for the interaction terms of RLTV with the level factor change and the slope factor change are significantly negative, suggesting that liability significantly muffs insurers' portfolio responses to these two factors. In addition, the coefficients on the interaction terms between RLTV and the curvature factor change are insignificant, suggesting that the liability does not affect portfolio (in)sensitivity to the interest rate curvature.

In Table 9, we further investigate the effect of risk aversion on portfolio responses. In Panel A of Table 9, the regression explanatory variables include one of the three factor changes, one of the three risk aversion proxies (SMALL, MUTUAL, and INDEPENDENT), as well as the interaction between risk aversion and the factor change. The estimated coefficients on the interaction terms between risk aversion proxies and factor changes tend to be insignificant, suggesting that portfolio response is not significantly affected by risk aversion. There are a few exceptions. For both P&C and life insurers, the coefficients for SMALL*ΔLevel are significantly positive. For life insurers, INDEPENDENT*ΔLevel is also significantly positive. These cases are further departure from the prediction that risk aversion reduces portfolio sensitivity. Finally, only in one case there is evidence consistent with the predicted effect of risk aversion – the coefficient of MUTUAL*ΔSLOPE is significantly negative.

We further report the results for the influence of liability on the risk aversion effect in Panel B of Table 9. Here, in each regression the explanatory variables include one of the three term structure factor changes, the product term of a risk aversion proxy with RLTV, and the three-way interaction term among the risk aversion proxy, RLTV, and the corresponding factor change. Our hypothesis is that liability interacts with risk aversion to reduce portfolio sensitivity to term structure changes. However, the evidence is weak. Out of a total of 18 regressions across insurer types, term structure factors, and risk aversion proxies, only in one case the coefficient of the three-way interaction term is significantly negative (LTV*MUTUAL*ΔSLOPE). In the only other case where the coefficient of interest is significant (LTV*SMALL*ΔLevel), the coefficient is positive.

Overall, there is evidence that liability reduces insurers' portfolio response to term structure factors, while the evidence for the risk aversion effect on portfolio response is weak.

5 Concluding Remarks

The preferred habitat hypothesis of term structure has attracted considerable attention due to its policy relevance. However, so far we have little empirical evidence that speaks to the microeconomic foundation of this theory. This study attempts to fill part of the gap. Using data for over three thousand property and life insurers, we detect habitat-like behavior in their government bond portfolios. The duration of insurers' claim liabilities is an important determinant of their bond portfolio durations. Further, insurers with stronger liability concerns exhibit more restrained portfolio response to term structure changes. However, we find no clear support for a habitat effect driven by insurers' risk preference and investment horizons. Our analysis highlights an important source of inelastic demand for government bonds and complements the macroeconomic studies that largely focus on the supply shocks to the term structure.

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.

Define $\hat{W}_t = W_t/B_t$. 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 $B_H = 1$, $W_H = \hat{W}_H$, and the investor's problem in (1) is equivalent to:

$$\text{Max}E_0(\frac{\hat{W}_H^{1-\gamma}}{1-\gamma}) \tag{15}$$

subject to the budget constraint:

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

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

$$J_t = E_t(J_{t+1}) = \hat{W}_t^{1-\gamma} E_t \frac{\left(\Pi_{\tau=t+1}^{H} \frac{R_{p\tau}}{R_{h\tau}}\right)^{1-\gamma}}{1-\gamma} \tag{16}$$

The log-linearized approximate solution to (15) 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 (16) becomes:

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

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,

$$\sigma_p^2 = \omega_\mathbf{t}'\mathbf{\Omega_t}\omega_\mathbf{t}$$

$$\text{Cov}(r_{pt+1}, x_{t+1}) = \omega_\mathbf{t}'\text{Cov}(\mathbf{r_{t+1}}, x_{t+1})$$

$$\text{Cov}(r_{pt+1}, r_{ht+1}) = \omega_\mathbf{t}'\text{Cov}(\mathbf{r_{t+1}}, r_{ht+1})$$

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 critically, the convergence property of the two hedging components (explained in the main text), are not straightforward.

A.2. Optimal Portfolio Weights with Liability

For t≤K, the portfolio return is $R_{pt} = \alpha_{t-1}R_{Kt} + (1-\alpha_{t-1})Z_{pt}$, where R_{Kt} is the gross return to the K-maturity bond from time t-1 to t, and $Z_{pt} = \sum_{m=1}^{M} \omega_{mt-1}R_{mt}$ 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 3.2 is $\omega^*_{mt} = \alpha_t + (1-\alpha_t)\omega_{mt}$ for the K-maturity bond, and $\omega^*_{mt} = (1-\alpha_t)\omega_{mt}$ for all other M-1 bonds. For t>K, the optimal portfolio weight is simply $\omega^*_{mt} = \omega_{mt}$.

To verify that ω^*_{mt} is the optimal solution to (4), we first note that for t≤K, the indirect utility function, combined with the wealth process, can be expressed as:

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

And the first order conditions with respect to the components of ω^*_{mt}, i.e., α_t and ω_{mt} (m=2,...M), are:

$$\frac{\partial J_t}{\partial \alpha_t} = W_t^{1-\gamma} E_t \left(F_t^{-\gamma} \left[\Pi^H_{\tau=K+1} Z_{p\tau}\right]^{1-\gamma} \left[\Pi^K_{\tau=t+1} R_{K\tau} - \Pi^K_{\tau=t+1} Z_{p\tau}\right]\right) = 0 \quad (17)$$

$$\frac{\partial J_t}{\partial \omega_{mt}} = W_t^{1-\gamma} E_t \left(F_t^{-\gamma}(1-\alpha_t) \left[\Pi^K_{\tau=t+2} Z_{p\tau}\right] \left[\Pi^H_{\tau=K+1} Z_{p\tau}\right]^{1-\gamma} \left[R_{mt+1} - R_{ft+1}\right]\right) = 0 \quad (18)$$

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

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

$$F_t = (1-\alpha_t)\Pi^K_{\tau=t+1} Z_{p\tau} \quad (19)$$

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):

$$E_t \left(Z_{pt+1}^{-\gamma} \left[\Pi^H_{\tau=t+2} Z_{p\tau}\right]^{1-\gamma} \left[R_{mt+1} - R_{ft+1}\right]\right) = 0 \quad (20)$$

$$E_t \left(Z_{pt+1}^{-\gamma} \left[\Pi^H_{\tau=t+2} Z_{p\tau}\right]^{1-\gamma} \left[R_{mt+1} - R_{Kt+1}\right]\right) = 0 \quad (21)$$

$$E_t \left(Z_{pt+1}^{-\gamma} \left[\Pi^H_{\tau=t+2} Z_{p\tau}\right]^{1-\gamma} \left[Z_{pt+1} - R_{Kt+1}\right]\right) = 0 \quad (22)$$

$$E_t \left(\left[\Pi^K_{\tau=t+1} Z_{p\tau}\right]^{-\gamma} \left[\Pi^H_{\tau=K+1} Z_{p\tau}\right]^{1-\gamma} \left[\Pi^K_{\tau=t+1} Z_{p\tau} - \Pi^K_{\tau=t+1} R_{Kt+1}\right]\right) = 0 \quad (23)$$

Here we continue to use the notation $Z_{pt} = \omega_{mt-1} R_{mt}$. (21) can be derived by applying (20) to both $R_{mt+1} - R_{ft+1}$ and $R_{Kt+1} - R_{ft+1}$. (22) can be derived from (21) using $Z_{pt} = \omega_{mt-1} R_{mt}$. Finally, (23) is a K-period multiplication of (22).

Then, the first order condition of (18) can be verified using (20) and (19). The first order condition of (17) can be verified using (23) and (19). 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 (4). 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 is 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 what is illustrated by the simple model above. The first issue is that the liability maturity may exceed the investment horizon, i.e., K>H. In this case, the time-H net wealth is $W_H - PV_t(L)$, where $PV_t(L)$ 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.

The second issue is that 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.

The third issue is that 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.

Appendix B. Claim Duration of P&C Insurers

When a policyholder claims a loss under an insurance policy, it is recorded by the insurer as its liability. Typically the claims are not paid off immediately, but are paid off gradually in subsequent years. The claim duration measures the weighted average time from the time of the claim to the time when the payment is made, in a way similar to the Macaulay duration of a bond:

$$\text{ClaimDur}_t = \frac{\sum_{k=1}^{N} \frac{\text{EP}_{t+k}}{(1+r_{t,k})^k} k}{\sum_{k=1}^{N} \frac{\text{EP}_{t+k}}{(1+r_{t,k})^k}} \tag{24}$$

where EP_{t+k} is the expected loss payment in year t+k for all losses claimed prior to the end of year t, and k=1, $\cdots$, N. For P&C insurance, the typical projection horizon is 9 years, i.e., N=9 (which means that losses are typically paid off within 9 years after they are claimed). $r_{t,k}$ is the time-t zero coupon yield with k-year maturity. The zero-coupon yields are estimated using the Nelson-Siegel-Svensson model. The model parameters are obtained from the Federal Reserve Board, as described in Section 3.4.

The key step to estimate claim duration is to project future loss payment, EP_{t+k}. For this, we adopt the "chain ladder" method, a popular practice in the insurance industry. In a given calendar year t, payments are made to losses incurred in the past τ years, $\tau = 0$, $\cdots$, 9. Denote the payment made in year t+k for losses incurred in year $t - \tau$ as $P_{t-\tau,t+k}$. Then $\text{EP}_{t+k} = \sum_{\tau=0}^{9} P_{t-\tau,t+k}$ (with $P_{t-\tau,t+k} = 0$ if $\tau + k > 9$). In practice, the projections are made for the cumulative loss payment since the accident/claim year. Let $C_{t-\tau,t+k}$ denote the cumulative loss payment from year $t - \tau$ to t+k for losses incurred in year $t - \tau$. Then $P_{t-\tau,t+k} = C_{t-\tau,t+k} - C_{t-\tau,t+k-1}$, and

$$\text{EP}_{t+k} = \sum_{\tau=0}^{9} (C_{t-\tau,t+k} - C_{t-\tau,t+k-1}) \tag{25}$$

Therefore, to project EP_{t+k} we need projections for the cumulative loss payments $C_{t-\tau,t+k}$, for τ=0, $\cdots$, 9. We use Part III of the Schedule P filings by P&C insurers to estimate $C_{t-\tau,t+k}$. Part III of Schedule P Part III reports cumulative losses paid in a given calendar year for losses incurred during each of the past 9 years as well as in the current year. For example, for the year of 2009 (last year of our sample), Part III of the Schedule P filing would provide the following information:

Accident	Development Year									
Year	0	1	2	3	4	5	6	7	8	9
2000	$C_{2000,2000}$	$C_{2000,2001}$	$C_{2000,2002}$	$C_{2000,2003}$	$C_{2000,2004}$	$C_{2000,2005}$	$C_{2000,2006}$	$C_{2000,2007}$	$C_{2000,2008}$	$C_{2000,2009}$
2001	$C_{2001,2001}$	$C_{2001,2002}$	$C_{2001,2003}$	$C_{2001,2004}$	$C_{2001,2005}$	$C_{2001,2006}$	$C_{2001,2007}$	$C_{2001,2008}$	$C_{2001,2009}$	
2002	$C_{2002,2002}$	$C_{2002,2003}$	$C_{2002,2004}$	$C_{2002,2005}$	$C_{2002,2006}$	$C_{2002,2007}$	$C_{2002,2008}$	$C_{2002,2009}$		
2003	$C_{2003,2003}$	$C_{2003,2004}$	$C_{2003,2005}$	$C_{2003,2006}$	$C_{2003,2007}$	$C_{2003,2008}$	$C_{2003,2009}$			
2004	$C_{2004,2004}$	$C_{2004,2005}$	$C_{2004,2006}$	$C_{2004,2007}$	$C_{2004,2008}$	$C_{2004,2009}$				
2005	$C_{2005,2005}$	$C_{2005,2006}$	$C_{2005,2007}$	$C_{2005,2008}$	$C_{2005,2009}$					
2006	$C_{2006,2006}$	$C_{2006,2007}$	$C_{2006,2008}$	$C_{2006,2009}$						
2007	$C_{2007,2007}$	$C_{2007,2008}$	$C_{2007,2009}$							
2008	$C_{2008,2008}$	$C_{2008,2009}$								
2009	$C_{2009,2009}$									

Under the "chain-ladder" method, the predicted future cumulative loss payment in year t+k (the "development year") for loss claimed in year t-τ ("accident year"), $C_{t-\tau,t+k}$, is the cumulative loss payment during the previous year $C_{t-\tau,t+k-1}$ times a "loss development factor" $f_{\tau+k}$:

$$C_{t-\tau,t+k} = f_{\tau+k} C_{t-\tau,t+k-1} \tag{26}$$

The loss development factor $f_{\tau+k}$ is "age-specific" and its time subscript τ+k refers to the age of the loss, calculated from the initial claim year t-τ to the payment year t+k. The loss development factor essentially measures the speed at which the cumulative loss payment increases when the age of the loss increases by one year. This speed is assumed to be same as that for the cumulative loss payment of the same age during the past 10 years up to (inclusive of) the filing year t. Therefore, given a loss age of g, the loss development factor can be estimated using the Schedule P data as:

$$f_g = \frac{\sum_{j=0}^{9-g} C_{t-g-j,t-j}}{\sum_{j=0}^{9-g} C_{t-g-j,t-j-1}} \tag{27}$$

Continuing to use the above Schedule P data of year 2009 as example, we have,

$$f_1 = \frac{\sum_{j=0}^{8} C_{2008-j,2009-j}}{\sum_{j=0}^{8} C_{2008-j,2008-j}}$$
$$f_2 = \frac{\sum_{j=0}^{7} C_{2007-j,2009-j}}{\sum_{j=0}^{7} C_{2007-j,2008-j}}$$
$$\ldots$$
$$f_9 = \frac{\sum_{j=0}^{0} C_{2000-j,2009-j}}{\sum_{j=0}^{0} C_{2000-j,2008-j}}$$

Once we have the loss development factor at various ages (f_1 to f_9), we can estimate the cumulative loss payment $C_{t-\tau,t+k}$ iteratively from $C_{t-\tau,t+k}$ and $f_{\tau+k}$. For example, for the loss claimed in year 2009-τ (τ taking a value between 0 and 9), we can estimate its cumulative payment iteratively, starting from 2010, to 2011, and so on:

$$C_{2009-\tau,2010} = f_{\tau+1} C_{2009-\tau,2009}$$
$$C_{2009-\tau,2011} = f_{\tau+2} C_{2009-\tau,2010}$$
$$\ldots$$
$$C_{2009-\tau,2018-\tau} = f_9 C_{2009-\tau,2018-\tau}$$

After obtaining $C_{t-\tau,t+k}$, we can then obtain the projection for EP_{t+k} following the expression (25), and then follow the expression (24) to estimate the claim duration ClaimDur_t.

References

Campbell, J.Y.,Y.L. Chan, and L.M. Viceira, 2003, A multivariate model of strategic asset allocation, *Journal of Financial Economics* 67, 4180.

Campbell, John Y. and Luis M. Viceira, 2001, Who should buy long-term bonds? *American Economic Review* 91, 99-127.

Detemple, J., and M. Rindisbacher, 2010, Dynamic Asset Allocation: Portfolio Decomposition Formula and Applications, *Review of Financial Studies* 23, 25-100.

Diebold, F., L. Ji, and C. L. Li, 2006, A Three-Factor Yield Curve Model: Non-Affine Structure, Systematic Risk Sources and Generalized Duration, in Klein, Lawrence, R. ed., Long-Run Growth and Short-Run Stabilization: Essays in Memory of Albert Ando. Cheltenham, U.K. and Northampton, Mass: Elgar, 240-274.

Diebold, F., and C. L. Li, 2006, Forecasting the term structure of government bond yields, *Journal of Econometrics* 130, 337-364.

Ferson, W., T. Henry, and D. Kisgen, 2006, Evaluating government bond fund performance with stochastic discount factors, *Review of Financial Studies* 19, 423-455.

Froot, K. A., D. S. Scharfstein, J. C. Stein, 1993, Risk Management: Coordinating Corporate Investment and Financing Policies, *Journal of Finance* 48, 1629-1658.

Greenwood, Robin, Samuel Hanson, and Jeremy C. Stein, 2010, A Gap-Filling theory of Corporate Debt Maturity Choice, *Journal of Finance* 76, 993-1028.

Greenwood, Robin, and Dimitri Vayanos, 2010a, Price pressure in the government bond market, *American Economic Review: Papers and Proceedings* 100 (2): 585-590.

Greenwood, Robin, and Dimitri Vayanos, 2010b, Bond supply and excess bond returns, *Working Paper*, London School of Economics.

Gürkaynak, R., B. Sack, and J. Wright, 2007, The U.S. Treasury yield curve: 1961 to the present, *Journal of Monetary Economics* 54, 2291-2304.

Hamilton, James D., and Jing Cynthia Wu, 2012, The effectiveness of alternative monetary policy tools in a zero lower bound environment, *Journal of Money, Credit & Banking* 44, 3-46.

Huang, J. and Y. Wang, 2010, Timing ability of government bond fund managers: Evidence from portfolio holdings, *Working Paper*, Penn State University.

Krishnamurthy, Arvind and Annette Vissing-Jrgensen, 2010, The aggregate demand for treasury debt, *working paper*.

Krishnamurthy, Arvind and Annette Vissing-Jrgensen, 2011, The effects of quantitative easing on long-term interest rates, prepared for Brookings Papers on Economic Activity.

Li, C., and M. Wei, 2012, Term Structure Modelling with Supply Factors and Applications to Federal Reserve's Large Scale Asset Purchase Programs Evaluation, Working Paper, Federal Reserve Board.

Lioui, A., and P. Poncet, 2001, On optimal portfolio choice under stochastic interest rates, *Journal of Economic Dynamics and Control* 25, 1841-1865.

Litterman, R., and J. Scheinkman, 1991, Common Factors Affecting Bond Returns, *Journal of Fixed Income* June Issue, 54-61.

Liu, J., 2007, Portfolio Selection in Stochastic Environments, Review of Financial Studies, 20, 1-39.

Modigliani, F., and R. Sutch, 1966, Innovations in interest rate policy, *American Economic Review*, 178-197.

Moneta, F., 2011, Measuring Bond Mutual Fund Performance with Portfolio Characteristics, *Working Paper*, Queen's School of Business.

Nelson, Charles R., and Andrew F. Siegel, 1987, Parsimonious modeling of yield curves, *Journal of Business* 60, 473-489.

Petersen, M., 2009, Estimating Standard Errors in Finance Panel Data Sets: Comparing Approaches, *Review of Financial Studies* 22, 435-480.

Smith, Clifford W., and Rene Stulz, 1985, The determinants of firms' hedging policies, *Journal of Financial and Quantitative Analysis* 20, 391-405.

Stulz, Rene, 1984, Optimal hedging policies, *Journal of Financial and Quantitative Analysis* 19, 127-140.

Swanson, Eric, 2011, Let's twist again: A high-frequency event-study analysis of operation twist and its implications for QE2, Brookings Papers on Economic Activity, Economic Studies Program, The Brookings Institution, vol. 42, pages 151-207.

Svensson, L.E.O., 1994, Estimating and interpreting forward rates: Sweden 19924, *NBER Working Paper* #4871.

Vayanos, Dimitri, and Jean-Luc Vila, 2009, A preferred-habitat model of the term structure of interest rates, *Working Paper*, London School of Economics.

Wachter, Jessica A., 2003, Risk aversion and allocation to long-term bonds, *Journal of Economic Theory* 112, 325-333.

Willner, R., 1996, A New Tool For Portfolio Managers: Level, Slope, and Curvature Durations, *Journal of Fixed Income,* June, 48-59.

Table 1: Summary Statistics on Insurers' Assets 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, value of stock and bond holding, value of bond holding, government bond holding as reported in the summary page of Schedule D, and the government bond holding in the sample. We also report the average duration of government bond portfolios. Panel A provides statistics on P&C insurers and Panel B provides statistics on life insurers. The sample period is from 1998 to 2009. The last row of each panel reports the unique numbers of insurers during the entire sample period, and the time series averages of the by-year asset characteristics.

	Number	Total	As Fraction of Total Assets (%)					Portfolio
	of	Assets	Invested	Bonds &	Bonds	Gov. Bonds	Gov. Bonds	Duration
Year	Insurers	($m)	Assets	Stocks		(Reported)	(Sample)	(Year)
Panel A: Property and casualty (P&C) insurers								
1998	1312	620.68	88.67	77.38	64.01	24.71	23.30	4.08
1999	1278	620.15	87.79	77.68	64.18	23.29	20.82	4.17
2000	1199	635.60	87.24	76.16	63.56	23.01	21.31	4.20
2001	1160	657.44	82.88	71.28	60.01	22.78	18.84	4.49
2002	1174	754.86	82.61	69.93	59.92	22.38	20.85	4.68
2003	1214	828.22	83.11	71.17	60.74	21.96	20.66	4.29
2004	1199	895.35	83.61	71.94	61.87	22.24	20.45	4.21
2005	1241	967.80	84.01	72.78	62.72	22.92	20.83	4.05
2006	1256	953.73	84.43	72.44	61.79	22.84	20.52	4.00
2007	1256	1001.65	85.17	73.17	62.25	22.19	20.31	4.11
2008	1222	1016.29	84.45	70.94	62.24	20.44	18.78	4.33
2009	1234	1102.71	84.09	72.37	62.87	20.53	18.24	4.21
All	2282	837.87	84.84	73.10	62.18	22.44	20.05	4.23
Panel B: Life insurers								
1998	542	3851.46	94.17	76.09	68.93	17.97	15.69	5.51
1999	525	4273.79	93.71	76.49	68.83	15.85	13.07	5.33
2000	483	4700.11	93.31	75.78	68.47	15.08	12.67	5.36
2001	481	5069.55	93.66	75.04	68.58	14.63	11.73	5.60
2002	481	5321.58	94.42	76.07	70.68	17.64	14.57	5.87
2003	469	5194.24	94.23	77.50	71.84	17.98	15.12	5.96
2004	448	6007.07	94.48	79.03	73.27	17.64	13.63	5.89
2005	424	6533.73	94.27	78.47	73.22	18.26	13.70	5.58
2006	404	7636.73	93.57	76.88	70.84	16.73	12.65	5.70
2007	387	8248.66	93.60	75.43	69.21	16.37	11.67	5.90
2008	355	8639.50	93.45	74.72	69.54	14.90	10.79	6.46
2009	349	9092.65	93.33	77.02	72.31	14.05	10.57	6.17
All	781	6214.09	93.85	76.54	70.48	16.42	14.64	5.77

Table 2: Bond Characteristics

This table reports annual statistics on sample government bonds. Government bonds are classified by issuers into Treasury and agency, and by maturity into three ranges: below 3 years, between 3 and 10 years, and beyond 10 years. We report the number of unique bonds in each category held by insurers and the total value of bonds in the category held by insurers as a percentage of the aggregate government bond portfolio value of insurers. Panels A and B report the statistics on bonds held by P&C insurers and life insurers separately. The last row of each panel reports the total number of unique bonds and the average fraction of value held by insurers in each bond category over the entire sample period of 1998 to 2009.

	Number of Unique Bonds Held by Insurers						Value of Bond Holdings As Fraction of Aggregate Government Bond Portfolio Value (%)				
	All	Treasury	Agency	Maturity Range			Treasury	Agency	Maturity Range		
Year	Bonds	Bonds	Bonds	< 3 yr	[3,10]	>10 yr	Bonds	Bonds	< 3 yr	[3,10]	>10 yr
Panel A: Bonds held by P&C insurers											
1998	5,106	355	4,751	906	3,396	804	28.90	71.10	10.29	50.81	38.91
1999	5,206	347	4,859	976	3,365	865	42.85	57.15	9.38	38.87	51.75
2000	5,114	295	4,819	1,056	3,194	864	28.44	71.56	10.20	50.86	38.94
2001	4,214	301	3,913	905	2,457	852	42.77	57.23	6.59	37.76	55.65
2002	4,135	282	3,853	912	2,338	885	40.65	59.35	9.32	37.39	53.29
2003	4,413	251	4,162	944	2,537	932	13.27	86.73	16.52	55.65	27.84
2004	4,399	254	4,145	1,039	2,505	855	19.18	80.82	19.49	50.26	30.25
2005	5,175	261	4,914	1,405	2,862	908	9.74	90.26	35.50	42.08	22.42
2006	5,778	268	5,510	1,784	2,958	1,036	13.49	86.51	37.39	39.16	23.45
2007	5,129	279	4,850	1,392	2,659	1,078	22.36	77.64	21.16	48.33	30.51
2008	3,357	279	3,078	686	1,661	1,010	27.18	72.82	16.00	45.34	38.66
2009	2,882	305	2,578	587	1,459	836	23.95	76.05	17.93	48.19	33.88
All	20,653	943	19,710	7,717	13,457	4,845	26.06	73.94	17.48	45.39	37.13
Panel B: Bonds held by life insurers											
1998	3,031	544	2,487	243	1,089	1,699	45.55	54.45	5.10	25.44	69.46
1999	2,851	472	2,379	229	1,170	1,452	38.30	61.70	3.34	23.46	73.20
2000	3,754	423	3,331	280	1,327	2,147	24.76	75.24	5.88	22.94	71.18
2001	2,233	392	1,841	277	932	1,024	21.79	78.21	5.70	14.79	79.51
2002	2,491	379	2,112	303	985	1,203	15.10	84.90	3.17	10.52	86.31
2003	2,608	345	2,263	311	1,055	1,242	13.06	86.94	2.16	10.55	87.29
2004	2,421	332	2,089	331	1,066	1,024	28.46	71.54	4.71	17.26	78.03
2005	2,629	315	2,314	453	1,173	1,003	23.30	76.70	4.18	23.76	72.06
2006	2,892	324	2,568	547	1,266	1,079	20.47	79.53	5.31	22.78	71.91
2007	2,621	326	2,295	446	1,202	973	26.52	73.48	4.14	25.16	70.70
2008	2,087	341	1,746	305	963	819	32.04	67.96	3.81	30.54	65.65
2009	1,898	385	1,513	280	866	752	45.21	54.79	6.21	29.21	64.58
All	11,100	1,049	10,051	2,558	5,556	5,164	27.88	72.12	4.48	21.37	74.16

Table 3: Operating and Financial Characteristics of Insurers

The table reports insurers' operating and financial characteristics that are used in analysis, for P&C and life insurers separately. LTV is the liability to investment ratio. ClaimDur is the claims duration. PctLife is the percentage of insurance premiums generated by life policies. We also report the percentages of insurers that are organized as mutual companies (MUTUAL) and that are not affiliated with parent groups or holding companies (INDEPENDENT).

	P&C Insurers				Life Insurers			
	LTV	ClaimDur	Mutual Insurers	Independent Insurers	LTV	PctLife	Mutual Insurers	Independent Insurers
Year	(%)	(Year)	(%)	(%)	(%)	(%)	(%)	(%)
1998	36.86	2.140	30.26	37.50	62.47	55.96	13.65	35.79
1999	37.57	2.176	29.73	33.96	61.54	56.27	14.10	36.38
2000	38.33	2.170	29.69	33.03	59.88	55.19	13.66	34.78
2001	39.01	2.247	29.66	31.38	65.62	56.15	12.27	32.64
2002	38.10	2.194	28.62	29.73	61.48	55.12	11.85	34.72
2003	38.33	2.268	28.50	29.32	64.65	54.36	12.79	33.90
2004	38.38	2.213	28.11	32.86	64.76	55.24	12.50	33.71
2005	38.23	2.119	29.57	34.97	64.27	56.23	10.38	34.67
2006	37.34	2.077	29.86	35.91	66.30	58.44	11.39	34.65
2007	36.67	2.098	30.57	35.67	65.83	56.77	10.59	36.18
2008	38.21	2.125	28.97	37.48	68.77	59.39	10.70	34.65
2009	35.72	2.219	28.28	31.69	68.65	58.99	11.46	31.81
Average	37.71	2.171	29.32	33.62	64.50	56.54	12.11	34.49

Table 4: Cross-firm and Within-firm Variations of Portfolio Duration

This table reports three measures on the variation of portfolio durations. The pooled variation is the standard deviation of portfolio durations over all firm-year observations. The cross-firm variation, is calculated as the time series mean of annual cross-firm standard deviation over the 12 sample years. The within-firm variation is calculate first by taking the standard deviation of portfolio duration for each insurer using all its time series observations, and then taking the average across insurers. We compute the statistics for all insurers as well as for P&C and life insurers separately. The sample period is from 1998 to 2009.

	All	P&C	Life
Pooled variation	2.66	2.24	3.31
Cross-firm variation	2.65	2.23	3.30
Within-firm variation	1.28	1.20	1.51

Table 5: Liability Habitat

This table reports the results of panel regression analysis on the liability habitat effect. The dependent variable is the portfolio duration. The explanatory variables include the cross-sectional decile rank of liability to investment ratio for P&C and life insurers separately (RLTV), Claims Duration (ClaimDur) for P&C insurers, the percentage of total premium generated by life policies (PctLife) for life insurers, and two liability habitat measures – RLTV*ClaimDur for P&C insurers and RLTV*PctLife for life insurers. All the regressions include year dummies to control for time fixed effects. The t-statistics reported in parentheses are computed using two-way clustered standard errors, by insurer and by year.

	P&C	Life	P&C	Life	P&C	Life
Intercept	4.61	5.86	4.14	5.37	4.81	5.31
	(84.16)	(53.36)	(56.26)	(34.07)	(67.34)	(34.07)
RLTV*ClaimDur	0.02					
	(2.93)					
RLTV*PctLife		0.27				
		(8.31)				
ClaimDur			0.16			
			(4.17)			
PctLife				1.83		
				(6.88)		
RLTV					0.05	0.32
					(3.44)	(8.59)

Table 6: Horizon Habitat

This table reports the results of panel regression analysis on the horizon habitat. The dependent variable is the portfolio duration. The explanatory variables include the cross-sectional decile rank of liability to investment ratio for P&C and life insurers separately (RLTV), the risk aversion proxies RA (SMALL, MUTUAL, and INDEPENDENT), and the interaction terms between RLTV and risk aversion proxies. SMALL is the cross-sectional decile rank for the inverse of firm assets, for P&C and life insurers separately. MUTUAL is an indicator for mutual insurers. INDEPENDENT is an indicator variable for insurers not affiliated with parent groups or holding companies. Panel A and B report the results of two different regression specifications. All the regressions include year dummies to control for time fixed effects. The t-statistics reported in the parentheses are computed using the two-way clustered standard errors, by insurer and by year. The sample period is from 1998 to 2009.

	Risk aversion proxy RA					
	SMALL		MUTUAL		INDEPENDENT	
	P&C	Life	P&C	Life	P&C	Life
	Panel A					
Intercept	5.46	9.06	4.75	6.66	4.89	7.13
	(53.48)	(46.79)	(76.88)	(73.39)	(68.48)	(78.48)
RA	-0.15	-0.52	0.13	0.73	-0.33	-1.14
	(-6.86)	(-14.06)	(1.35)	(2.23)	(-3.37)	(-5.40)
	Panel B					
Intercept	5.62	8.77	4.60	5.27	4.79	5.88
	(34.03)	(18.01)	(55.36)	(32.93)	(50.62)	(25.89)
RLTV	-0.02	0.03	0.03	0.31	0.02	0.26
	(-0.80)	(0.43)	(1.72)	(8.47)	(0.99)	(6.09)
RA	-0.16	-0.52	0.17	0.54	-0.35	-1.32
	(-5.64)	(-7.39)	(0.96)	(1.24)	(-2.29)	(-4.89)
RLTV*RA	-0.01	0.01	-0.01	-0.01	0.01	0.10
	(-0.17)	(1.01)	(-0.20)	(-0.06)	(0.33)	(1.77)

Table 7: Preferred Habitat: Within vs. Between Effects

This table reports the results of panel regression analysis that decomposes the liability habitat and the horizon habitat each into a within-insurer effect and a between-insurer effect. We require an insurers to have at least three years of valid observations to be included in the regressions. Panel A reports the results of the within-effect panel regression using de-meaned dependent and explanatory variables. A de-meaned variable is the raw variable minus its time series mean for a given insurer. The dependent variable is the demeaned portfolio duration. The explanatory variables include de-meaned insurer characteristics LTV, ClaimDur, PctLife, lnASSET (log of total assets), as well as interaction terms LTV*ClaimDur, LTV*PctLife , and LTV*lnASSET. The regressions include year dummies to control for time fixed effects. The t-statistics are computed using standard errors clustered by insurer and year. Panel B reports the results of the between-effect cross-sectional OLS regressions. The dependent variable is the mean portfolio duration of an insurer. The explanatory variables include insurer-specific mean characteristics LTV, ClaimDur, PctLife, lnASSET, as well as the interaction terms LTV* ClaimDur, LTV* PctLife, and LTV*lnASSET. The t-statistics are computed using the White heteroscedasticity-consistent standard errors. The sample period is from 1998 to 2009.

	P&C	Life	P&C	Life	P&C	Life	P&C	Life	P&C	Life
	Panel A: The Within Effect									
de-meaned LTV	0.21	0.70							-0.06	3.64
	(1.14)	(1.98)							(-0.02)	(1.54)
de-meaned ClaimDur			0.01							
			(0.03)							
de-meaned PctLife				1.26						
				(2.54)						
de-meaned lnASSET					0.09	0.61			0.09	0.61
					(1.37)	(4.41)			(0.99)	(4.14)
de-meaned LTV*ClaimDur							0.02			
							(0.37)			
de-meaned LTV*PctLife								0.81		
								(1.91)		
de-meaned LTV*lnASSET									0.01	-0.18
									(0.08)	(-1.37)
	Panel B: The Between Effect									
Intercept	4.03	3.11	3.65	4.37	-0.55	-7.17	3.94	4.40	-1.72	-5.44
	(50.65)	(13.03)	(39.68)	(24.65)	(-1.33)	(-9.54)	(62.72)	(28.90)	(-2.19)	(-2.65)
mean of LTV	0.39	4.02							2.52	-0.06
	(2.11)	(11.17)							(1.38)	(-0.02)
mean of ClaimDur			0.26							
			(6.35)							
mean of PctLife				2.16						
				(8.06)						
mean of lnASSET					0.26	0.67			0.33	0.53
					(11.58)	(17.02)			(7.34)	(4.56)
mean of LTV*ClaimDur							0.28			
							(6.53)			
mean of LTV*PctLife								2.99		
								(9.95)		
mean of LTV*lnASSET									-0.16	0.06
									(-1.56)	(0.39)

Table 8: Portfolio Response to Term Structure Changes and Effect of Liability

This table reports the results of panel regression analysis on the sensitivity of portfolio NS durations to term structure changes and the effect of liability. The dependent variable is the change in one of the three Nelson-Siegel (NS) portfolio duration measures during a year. In Panel A, the explanatory variable is the one-year change (ΔF) of one of the three NS term structure factors, ΔLevel, ΔSlope, and ΔCurv. In Panel B, the explanatory variables additionally include a cross-sectional decile ranking RLTV for LTV (for P&C and life insurers separately) and the interaction term between RLTV and the term structure factor change. The t-statistics reported in the parentheses are computed using the two-way clustered standard errors, by insurer and by year. The sample period is from 1998 to 2009.

	P&C			Life		
ΔF	ΔLevel	ΔSlope	ΔCurv	ΔLevel	ΔSlope	ΔCurv
	Panel A: Baseline Regressions					
Intercept	-0.53	-0.24	-0.21	-0.22	-0.12	-0.10
	(-0.58)	(-0.45)	(-0.50)	(-0.38)	(-0.33)	(-0.38)
ΔF	3.33	0.14	-0.03	2.19	0.07	-0.01
	(2.73)	(1.78)	(-0.30)	(2.80)	(1.66)	(-0.06)
	Panel B: Effect of Liability					
Intercept	-0.52	-0.26	-0.21	-0.32	-0.15	-0.14
	(-0.58)	(-0.49)	(-0.52)	(-0.43)	(-0.34)	(-0.41)
ΔF	3.22	0.13	-0.02	2.79	0.11	-0.01
	(2.66)	(1.73)	(-0.18)	(2.58)	(1.76)	(-0.18)
RLTV	-0.01	0.01	-0.01	0.02	0.01	0.01
	(-0.02)	(0.33)	(-0.01)	(1.09)	(0.48)	(0.59)
RLTV*ΔF	-0.02	-0.01	-0.01	-0.13	-0.01	0.01
	(-2.33)	(-1.65)	(-1.41)	(-1.87)	(-1.89)	(0.49)

Table 9: Effect of Risk Aversion on Portfolio Response to Term Structure Changes

This table reports the results of panel regression analysis of the risk aversion effect on portfolio response to term structure changes. The dependent variable is the change in one of the three Nelson-Siegel (NS) portfolio duration measures during a year. In Panel A, the explanatory variables include the one-year change (ΔF) of one of the three NS term structure factors, ΔLevel, ΔSlope, and ΔCurv, one of the three risk aversion measure RA (SMALL, MUTUAL, and INDEPENDENT), and the interaction term between RA and ΔF. In Panel B, the explanatory variables include ΔF, the product of RLTV and RA, and the three-way product term of RLTV, RA, and ΔF. RLTV is the cross-sectional decile rank of liability to investment ratio LTV. SMALL is the cross-sectional decile rank for the inverse of firm assets. MUTUAL is an indicator for mutual insurers. INDEPENDENT is an indicator variable for insurers not affiliated with parent groups or holding companies. The t-statistics reported in the parentheses are computed using the two-way clustered standard errors, by insurer and by year. The sample period is from 1998 to 2009.

Panel A: Effect of Risk Aversion						
	P&C			Life		
ΔF	ΔLevel	ΔSlope	ΔCurv	ΔLevel	ΔSlope	ΔCurv
	Risk aversion proxy (RA): SMALL					
Intercept	-0.54	-0.25	-0.22	-0.04	-0.04	-0.03
	(-0.65)	(-0.54)	(-0.60)	(-0.16)	(-0.22)	(-0.24)
ΔF	2.88	0.16	-0.04	1.23	0.01	0.01
	(2.31)	(0.91)	(-0.55)	(2.48)	(0.29)	(0.30)
RA	0.28	0.10	0.17	-3.29	-1.39	-1.28
	(0.11)	(0.06)	(0.15)	(-0.79)	(-0.58)	(-0.61)
RA*ΔF	0.08	-0.01	0.01	0.18	0.01	-0.01
	(1.90)	(-0.76)	(0.61)	(1.94)	(1.01)	(-0.43)
	Risk aversion proxy (RA): MUTUAL					
Intercept	-0.53	-0.25	-0.22	-0.21	-0.11	-0.10
	(-0.57)	(-0.47)	(-0.53)	(-0.35)	(-0.32)	(-0.37)
ΔF	3.24	0.15	-0.03	2.27	0.07	-0.01
	(2.56)	(0.83)	(-0.31)	(2.84)	(0.67)	(-0.12)
RA	0.55	2.04	1.52	-7.80	-2.53	-0.41
	(0.03)	(0.23)	(0.24)	(-0.23)	(-0.17)	(-0.04)
RA*ΔF	0.30	-0.03	0.00	-0.63	-0.03	0.03
	(0.85)	(-4.42)	(0.07)	(-1.21)	(-0.91)	(1.27)
	Risk aversion proxy (RA): INDEPENDENT					
Intercept	-0.54	-0.24	-0.21	-0.16	-0.08	-0.07
	(-0.58)	(-0.45)	(-0.51)	(-0.31)	(-0.27)	(-0.33)
ΔF	3.29	0.15	-0.03	1.91	0.05	0.01
	(2.56)	(0.81)	(-0.37)	(2.77)	(0.64)	(0.01)
RA	6.08	-0.32	0.06	-16.99	-10.50	-7.89
	(0.37)	(-0.06)	(0.01)	(-0.70)	(-0.99)	(-0.89)
RA*ΔF	0.14	-0.02	0.02	0.83	0.04	-0.01
	(0.39)	(-1.26)	(1.08)	(1.73)	(0.79)	(-0.40)

Panel B: Joint Effect of Risk Aversion and Liability						
	P&C			Life		
ΔF	ΔLevel	ΔSlope	ΔCurv	ΔLevel	ΔSlope	ΔCurv
	Risk aversion proxy (RA): SMALL					
Intercept	-0.60	-0.28	-0.23	-0.22	-0.11	-0.10
	(-0.71)	(-0.60)	(-0.64)	(-0.38)	(-0.33)	(-0.39)
ΔF	2.81	0.14	-0.02	2.13	0.07	-0.01
	(2.30)	(0.86)	(-0.28)	(2.46)	(0.74)	(-0.08)
RLTV*RA	0.33	0.20	0.10	0.02	-0.02	0.01
	(3.89)	(0.56)	(0.40)	(0.03)	(-0.07)	(0.01)
RLTV*RA*ΔF	2.42	-0.01	-0.03	0.31	-0.03	0.01
	(3.03)	(-0.11)	(-0.34)	(0.29)	(-0.35)	(0.11)
	Risk aversion proxy (RA): MUTUAL					
Intercept	-0.53	-0.25	-0.21	-0.21	-0.11	-0.10
	(-0.59)	(-0.47)	(-0.53)	(-0.35)	(-0.32)	(-0.37)
ΔF	3.20	0.15	-0.03	2.27	0.07	-0.01
	(2.57)	(0.82)	(-0.29)	(2.84)	(0.67)	(-0.10)
RLTV*RA	0.55	0.59	0.26	-1.52	-0.41	-0.14
	(0.14)	(0.76)	(0.61)	(-0.30)	(-0.38)	(-0.20)
RLTV*RA*ΔF	10.07	-0.48	-0.15	-12.01	-0.49	0.33
	(1.48)	(-2.35)	(-0.46)	(-1.54)	(-0.93)	(0.87)
	Risk aversion proxy (RA): INDEPENDENT					
Intercept	-0.53	-0.23	-0.21	-0.21	-0.10	-0.09
	(-0.57)	(-0.44)	(-0.50)	(-0.37)	(-0.31)	(-0.37)
ΔF	3.26	0.14	-0.03	2.09	0.07	-0.01
	(2.62)	(0.80)	(-0.34)	(2.71)	(0.68)	(-0.02)
RLTV*RA	0.08	-0.58	-0.41	-0.76	-0.94	-0.52
	(0.02)	(-0.33)	(-0.33)	(-0.21)	(-0.56)	(-0.43)
RLTV*RA*ΔF	5.64	-0.26	0.23	6.97	0.21	-0.17
	(0.86)	(-0.94)	(0.71)	(1.33)	(0.39)	(-0.64)