Interest Rates and the Duration Matching of Life Insurance Companies*

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April 4, 2021

Abstract

I study duration-matching behavior by life insurers in response to interest rate movements. Previous literature finds the evidence that the duration gap between assets and liabilities is negatively correlated to interest rates, which is interpreted as ex post duration adjustment. I further hypothesize that value-maximizing life insurers have incentives to make pre-emptive matching in anticipation of future interest rates. I use the term spread of the yield curve as the indicator of expected change in interest rates and show that U.S. life insurers actively shorten the durations of their asset portfolios reacting to an increasing in both the interest rate level and expected future interest rates proxized by the term spread. To identify the causal relation, I exploit the monetary policy shock associated with 2013 taper tantrum in the difference-in-differences analysis. Consistent with the hypotheses, there is a negative impact of the tape tantrum on the asset duration of life insurers comparing with property & casualty insurers who are not subject to the pressure of mismatched asset-liability duration.

Keywords: Duration matching, Interest rate risk, Life insurance companies, Risk management

JEL classification: G11, G12, G22, G23, G31, G32

*I am greatly indebted to my advisors Ajay Subramanian and George Zanjani for their invaluable guidance. I am also grateful to my dissertation committee members Hamed Amini, Scott Murray and Liang Peng, for their generous advice and support. I thank Vikas Agarwal, Daniel Bauer, Mark Chen, David Eckles, Raymond Kim, Divya Kirti, Gerald Gay, Anthony Green, Andre Liebenberg, Xiaochen Jing, Dalida Kadyrzhanova, Robert Klein, Chuck Nyce, Robert Hoyt, Erzo Luttmer, Lawrence Powell, Joan Schmit, Stathis Tompaidis, Yuri Tserlukevich, and other seminar participants at Georgia State University, Michigan State University, University of Georgia, FMA 2020, World Risk and Insurance Economics Congress 2020, Actuarial Research Conference 2020 for valuable discussions and comments. A.M. Best Company, NAIC and S&P global market intelligence own the copyright of their respective data, which I use with their permission. In particular, I gratefully acknowledge A.M. Best Company generously provides financial strength ratings for free. All errors are mine.

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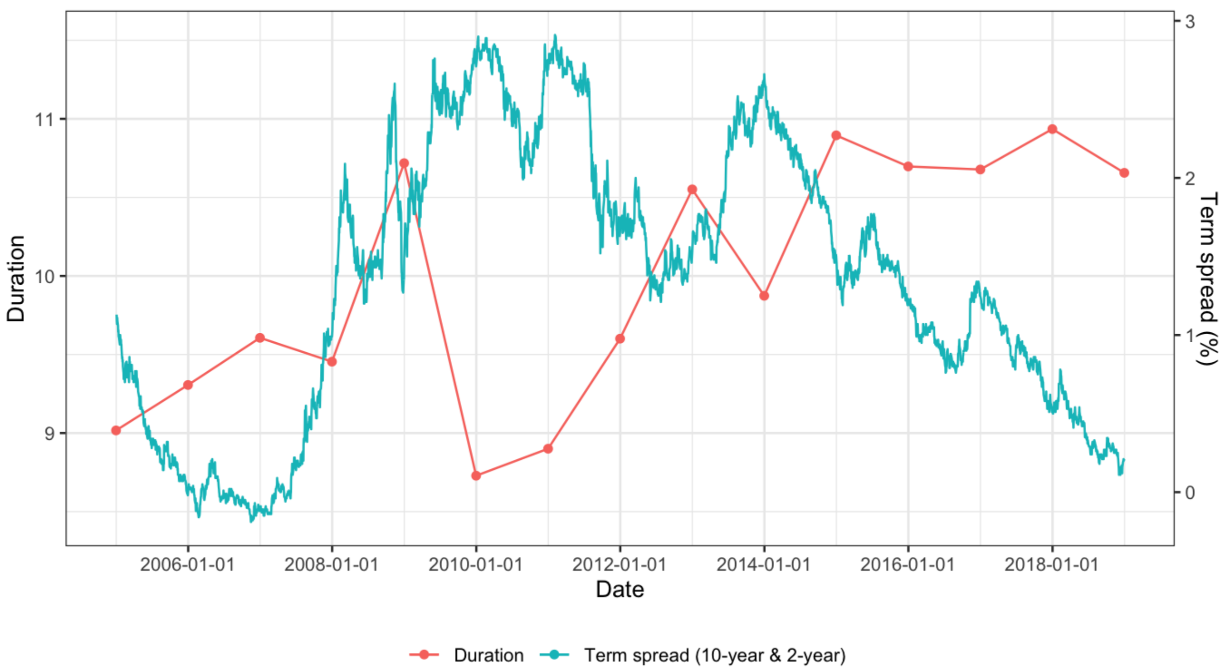
1 Introduction

Life insurers are exposed to interest rate risk because of the duration mismatch between assets and liabilities. Interest rate risk management aimed at bridging the duration gap can potentially immunize their portfolios against fluctuations in interest rates. Regulators and rating agencies also exert pressure on insurers to manage their risk exposures. The National Association of Insurance Commissioners (NAIC) ties risk-based capital (RBC) surcharges to interest rate risk. The rating agency, A.M. Best considers the surplus value of insurers as an important indicator of financial strength. To hedge the interest rate risk exposure, life insurers strategically manage asset portfolios, which primarily consist of bonds, to align the durations of their assets with liabilities. Sophisticated life insurers also trade interest rate derivatives to appropriately manage their asset risk exposures.

Figure 1: Average duration of industrial bond holdings

The figures illustrates the evolution of the aggregate duration of life insurance companies with interest rate movements. The red dots indicates the average duration of the bond holding of the life insurance industry. The blue curve is the term spread of between 10-year and 2-year treasury yields.



Given the asset-liability portfolios of life insurers are typically mismatched[1], how life insurers' matching behavior reacts to interest rate movements is important and of interest. Previous literature finds the evidence that asset duration is negatively associated with interest rates.

[1]The argument of life insurers mismatching is mentioned in CGFS (2011), EIOPA (2014), Domanski et al, (2015), Paulson and Rosen (2016) and Koijen and Yogo (2017).

Domanski et al. (2017) documents that German life companies hunted for the longer duration assets when long-term interest rates in Europe fell sharply in 2014 to historically low levels. Ozdagli and Wang (2019) show the same hedging pattern in the U.S. life insurance industry. The aforementioned studies interpret the matching pattern negatively associated with interest rates as *ex post* duration adjustment. However, life insurers still sustain surplus loss upon downward interest rates although *ex post* matching duration can the enlarged duration gap afterward. Such surplus loss caused by mismatched duration can avoid or reduce if life insurers are able to close the duration gap beforehand in anticipation of *future* interest rates. Therefore, I hypothesize that in addition to *ex post* duration adjustment life insurers also have the incentive to match duration *ex ante* according to their expectations of future interest rates. Based on expectations theory and its supportive literature[2], I use the term spread of the treasure yield curve as the market sign that life insurers perceive to form their expectations of future interest rates and investigate its relation with the matching behavior of life insurers. The preliminary evidence in Figure 1 shows a negative correlation between the term spread and the aggregate duration of life insurance industry, which suggests a systematic matching pattern associated with the expectation of future interest rates.

Motivated by this evidence, this paper disentangles different impacts of interest rate on life insurers and proposes the two channels underlying the duration-matching mechanism, *ex post* adjustment responding to the interest rate level and *ex ante* adjustment responding to the market signal of future rates, the term spread. *Ex post* adjustment is to rematch the duration gap which varies with interest rate movements because of the convexity difference between the asset and the liability portfolio[3]. *Ex ante* matching is able to alleviate surplus loss (exploit surplus gain) from downward (upward) interest rate movements by making pre-emptive adjustment according to the market signal of future rates. Despite the difference of two types of adjustment behavior, they are both driven by the incentive that life insurers choose an optimal duration gap to maximize their surplus value. Moreover, financially constrained insurers expose themselves to a large interest rate risk by choosing a relatively large duration gap relative to non-constrained insurers. Such role that the financial constraint play in terms of risk-taking is verified empirically and also consistent with the finding of Rampini et al. (2019) in bank holding companies.

I verify the hypothesized channels of duration matching in three steps. First, I construct a representative asset-liability portfolio for life insurers, and shows that they are, indeed, prompted

[2]The argument of validation of expectations theory (and rational expectations theory) is unsettled. The justification of using the term spread to proxize the market signal of future interest rates is detailed in Section 2.2.

[3]For life insurance company, the duration of the liability portfolio is more sensitive to interest rates than the duration of the asset portfolio. See Domanski et al. (2017) and Gilbert (2017).

to systematically adjust duration reacting to interest rate movements. Then, I verify the stylized facts of matching behavior testing on the U.S. life insurance industry during the period 2004-2018. Finally, I exploit the monetary policy shock, 2013 taper tantrum, as the identification strategy to copy with potential reversal relation between bond trading and interest rate movements.

To confirm the incentive of life insurers to match duration, I study how the duration gap varies with interest rates without active duration adjustment. To get around the lack of liability information for individual companies, I constructs an asset-liability portfolio using industry aggregate data from several different sources and use it as a representative portfolio for individual insurers. Using the maturity information of assets and insurance policies, I project its cash flow so as to evaluate the effective duration gap with the actual interest rates of treasury securities in 2015. I shows that the effective duration gap is negatively correlated to the level of the yield curve. This provides the rationale to maintain a proper duration gap with the change in the interest rate level. Similarly, I shows the negative association between the term spread and the future duration gap up to night-month ahead. It is long enough to incentivize life insurers to make pre-emptive duration adjustment.

The primary challenge of examining the hypothesized matching behavior reacting to interest rate movements is to compute an appropriate measure of duration adjustment. Because life insurance companies are primarily liability-driven, I consider the duration adjustment to be from the asset side and control the interest rate exposure in liabilities, instead of using a vague measure of the duration gap caused by the lack of liability information. I also incorporate the derivative trading into duration adjustment by combined with detailed derivative holding information with the computation function of the Bloomberg Swap Manager. The hypothesized negative association of the asset duration with the interest rate level and the term spread is verified using the new asset duration measure. Moreover, I show that the life insurers actively increase asset duration on average by 0.22 year in response to the 1% decrease in the interest rate level and 0.19 year in response to the 1% decrease in the term spread. The pre-emptive duration adjustment results more from the change in the long-end of yield curve. Cross-sectionally, I find that the derivative users adjust duration more intensively compared with non-derivative users, which implies that trading derivatives could be more efficient to manage the interest rate risk than structuring bond portfolios.

Although duration matching behavior reacts to interest rate movements, it could also affect interest rates given that insurers have significant holdings in corporate and treasury bonds[4]. To address the possible reversal causality, I employ the 2013 taper tantrum as the identification

[4]Murray and Nikolova (2020) demonstrates that insurers' investment demand for corporate bonds affect their price. Greenwood and Vayanos (2018) document a strong effect of pension and insurance company assets on the long end of the yield curve.

strategy and further test the hypothesized association with a DID identification. The interest rate shock was caused by the sudden news from Bernanke that Federal Open Market Committee (FOMC) was considering a potential plan of quantitative easing. It led to the rapid increasing of treasury yields and the market's anticipation of upward future yields. In the DID analysis, I first compare the treatment impact of the taper tantrum on highly exposed life insurers to the interest rate risk with that on the life insurers with relatively low interest rate risk exposure. I also compare the group of life insurers with the group of property & causality (P&C) insurers. P&C insurance companies is the valid control group because the duration of their liabilities is much shorter than that of life insurance companies so that they are much less exposed to large fluctuations in the durations of their asset-liability portfolios in response to interest rate movements. With a continuous DID specification (Acemoglu et al., 2004) I show that that the increasing of highly exposed life insurers in duration exposure after shock is indeed less than that of mildly exposed life insurers. Such reduction on duration exposure is positively correlated with the proportion of long-term liabilities and also with the term spread. The same DID results appears in the comparison between life insurers and P&C insurers as well.

Structure of the paper: In the following content, Section 2 introduces the framework of duration matching and the predictive function of the term spread verified by previous literature. Section 3 specifies two channels of duration matching and develops main hypotheses of the association between duration adjustment and interest rate movement. Section 4 describes the data and constructs duration measures. Section 5 verifies the causality underlying matching channels and Section 6 exhibits the empirical testing of main hypotheses. Section 7 provides the identification strategy investigating taper tantrum 2013. Section 8 concludes.

2 Preliminary

2.1 The framework of duration matching

Life insurers feature long-term liability portfolio including life insurance[5] (whole life and universal life policies) and annuities which provide long-term and fixed rate payments. The liability duration for a life insurance company is typically more than 20 years. Therefore, they would expose to severe duration risk if these long-term and fixed liability payments are not well matched by assets or interest rate derivatives. The marginal present value change of the assets caused by the change in the interest rate will be considerably different from that in the liabilities. In other words, the surplus value is exposed to the interest rate fluctuation if the interest rate risk exposure in the liability is not well hedged by the asset and derivatives. Other reasons to match

[5]Most term life insurance policies last 10, 20 or 30 years, but many companies offer additional five- or 10-year increments, some up to 35 or 40 year terms.

the duration come from the aspects of the rating agency and the regulator. Well-matched duration avoid the volatility of surplus so that enhance life insurers' financial strength, which rating agencies, for instance, A.M. Best[6], monitor closely. National Association of Insurance Commissioners (NAIC) ties risk-based capital (RBC) surcharges to interest rate risk, so high interest rate interest risk contributes to a higher RBC, which pushes insurers close to required minimal RBC ratio[7] (Lombardi, 2006). Moreover, hedging interest rate risk can ensure life insurers have sufficient internal funds available to take advantage of attractive investment opportunities, especially when external sources of finance are more costly than internally generated funds (Froot et al., 1993).

To match the dollar duration of asset and liability portfolios, life insurers have to actively hold a large proportion of long-term bonds in their asset portfolios, such as long-term treasury bonds. Life insurers can also employ the off-balance-sheet approach, using interest rate derivatives, to match the long duration of the liability. For instance, fixed payments contracted in insurance policies can be exchanged for floating cash flows using receive-fixed and pay-floating swaps or interest rate floors, thereby being immunized against the fluctuation in the interest rate.

If duration is perfectly matched, or within some tolerance, the change in the value of the assets on some basis (economic, market value or book value) will be equal to that in the liabilities with the fluctuation of the interest rate. However, this is not an easy task. First, duration matching is costly. The long-term nature of life insurance and annuities requires assets with long maturity to match duration while long-term bonds (main assets of life insurers) with the favorable return is not always available. Ozdagli and Wang (2019) also propose a model of duration-matching under adjustment costs to explain the mechanism behind duration adjustment reacting to interest rate changes. They suggest German life insurers balance the extent of duration matching against the adjustment cost from bond acquisitions and disposals. Moreover, other than hedging duration risk, there are other ALM objectives that insurers need to comply with, such as maximizing investment income. Because of these reasons, life insurers might choose to take some level of interest rate risk and live with a duration gap to some extent.

Based on the framework of duration matching, this paper proposes the two channels through which life insurers are impacted to the movement of the interest rate and adjust the matching behavior accordingly. The first one explains life insurers' incentive to adjust the duration gap based on the current interest rate level. Because of the convexity difference between the asset and liability portfolio, the interest rate fluctuation causes life insurers to deviate from the optimal level of duration matching. As a result, they are exposed to more or less the interest rate risk

[6]AM Best is the only global credit rating agency with a unique focus on the insurance industry. Best's Credit Ratings, which are issued through A.M. Best Rating Services, Inc., are a recognized indicator of insurer financial strength and creditworthiness.

[7]RBC ratio is defined as total adjusted capital divided by risk-based capital.

than what they choose to bear. So they would like to restore the duration-matching to the optimal level. The second channel specifies the process that life insurers adjust duration ex ante driven by their beliefs of the future interest rate. Life insurers are subject to the interest rate risk is because the present value of surplus is exposed to the interest rate fluctuation in the existent of the duration gap. If life insurers can foresee the change in the future interest rates, by adjusting the duration gap ex ante they have the opportunity to mitigate the surplus loss during the adverse interest rate fluctuation (or enhance surplus value during the favorable interest rate fluctuation). For instance, anticipating the decline of the interest rate they can close the duration gap ex ante, which would otherwise reduce the value of surplus.

2.2 The term spread as the indicator of the expected interest rates

It is well accepted that the term spread contains the predictive information of the future economy. For instance, the flat yield curve implies the subsequent economic recessions. The rational expectations theory takes a further steps by hypothesizing that the term spread, which reflects the market expectations of forward rates, is an efficient forecast of the future interest rates. However, the validation of rational expectational theory is bewildering with some supportive evidence among others reject its predicative value. The argument needed by this paper to build up hypotheses is that life insurers as market participants form their expectation of future interest rates based on the term spread. In other words, this paper takes the stand that the slope of the yield curve is a valid market indicator of the change in future interest rates. In the following paragraph it is going to review relevant literature and derive the desire conjecture.

Among the evidence that supports the expectations theory, Cook and Hahn (1990) found the evidence of forecasting power for short-rates. Their testing shows that yield curve from one to five years can forecast the one-year rate over the following three or four years. The finding in Campbell and Shiller (1991) also confirmed the forecasting power for the short-term rates(maturities less than one year). They prove that when yield spreads between the long-term and the short-term bonds is relatively high, short-term rates tend to rise over the lifetime of the long-term bonds. The supportive evidence about long-term rates is provided by Froot (1989), where it uses the survey data by Goldsmith-Nagan that reports the expectations of financial-market participants[8]. It finds that at long maturities the surveyed expectation of interest rates is consistent with the yield curve spread. In addition, Longstaff (2000) argues the expectations hypothesis cannot be ruled out theoretically by showing that the hypothesis can be consistent with the absence of arbitrage if markets are incomplete. Therefore, with the literature just listed it is safe to claim that the term spread reflects the expectation about the future rates, which

[8] The expectation of interest rates surveyed by Goldsmith-Nagan includes three-month treasury bills, three-month Eurodollar deposits, twelve-month treasury bills, the Bond Buyer index, and the thirty-year mortgage.

would be realized in actual interest rates if the expectation is rational.

With the literature just listed, it aims to justify using the term spread as a market indicator of the expectation of future rates, which would be consistent with actual interest rates if the expectation is rational. However, it cannot claim that the proxy is ideal given that the coexistence of the literature that debunk the expectations theory. In Section 5, it will further demonstrate the comovement of the term spread and the duration gap, which makes it convincing that life insurers react to the varying of the term spread.The following two subsections elaborate how life insurers are affected to the interest rate movement through the two channels and hypothesize how they adjust their duration-matching accordingly.

3 Duration adjustment channels

3.1 Duration matching, the interest rate level and convexity

The difference of convexity between the asset and the liability portfolio plays the key role of driving the calibration of portfolio duration responding to the interest rate change. Because of the convexity difference, even if an insurer' duration is already matched to a proper extent, the change of the interest rate level would change the duration of the asset and the liability portfolio differently, thereby enlarging or reducing the duration gap. The varying duration gap with the interest rate level makes it necessary for life insurers to adjust duration dynamically. For instance, the duration gap between assets and liability (liability duration being larger) is widened as interest rates decline (Domanski et al., 2017 and Gilbert, 2017). Specifically, this is because the duration of liabilities increases by a greater amount than the duration of assets. The policyholder's behavior amplifies this impact because the likelihood of surrender and lapse reacts to the interest rate changes[9]. In a word, the decline of the interest rate exposes life insurers to higher interest rate risk because of the convexity of the asset-liability portfolio and also the policyholder's behavior. To alleviate interest rate risk resulted from a widened duration gap, life insurers should either increase dollar duration in bond portfolios or purchase the interest rate derivative. In contrast, if the interest rate continue rising, the duration of liabilities decreases by a greater amount than the duration of assets, which reduces the duration gap. In other word, because of the convexity difference between assets and liabilities the rising of the interest rate level mitigates duration mismatching without rebalancing portfolios. So life insurers are less constrained to maintain the level of duration in the asset portfolio and are able to cater for

[9]For instance, in the environment of the declining interest rates, policyholders are more likely to hold on to their insurance polices because there is lack of more profitable investment opportunities in the market. Ozdagli and Wang (2019) finds the positive relationship between interest rates and surrender/lapse rates. Kubitza et al. (2020) also provide empirical evidence that an increase in interest rates leads to more policy surrender activity, and then estimate the magnitude of forced asset sales and its sensitivity in a calibrated model.

other ALM objectives.

In a word, the adverse interest rate fluctuation causes life insurers to derivate from the extent of duration-matching to which they would like to choose because of the different convexity nature of the asset and liability portfolio. To dynamically rematch their duration, life insurer adjust the duration in the asset side in a negative pattern correlated to interest rates, the evidence of which is found in both Germany and U.S. life industry by Domanski et al. (2017) and Ozdagli and Wang (2019). I summarize the matching behavior attributed to *ex post* adjustment in Hypothesis 3.1.

> Hypothesis 1: As the increasing (decreasing) of the interest rate level, life insurers decrease (increase) the dollar duration in assets by trading bonds or/and interest rate derivatives.

3.2 Ex-ante duration matching and term structure factors

Driven by their beliefs of the future change in the interest rate life insurers might have the incentive to adjust their asset duration ex-ante, either through structuring asset portfolios or trading interest rate derivatives. The reason that prompts the ex-ante adjustment is that life insures can avoid the suppressing of surplus in the case of adverse interest rate changes or make use of favorable interest rate changes to enhance their surplus. For instance, it is already discussed that the declining events of the interest rate can enlarge or generate[10] the duration gap because of the convexity difference between the asset and the liability portfolio. The declined interest rate also causes surplus to be suppressed because of the longer duration of the liability. Specifically, the larger dollar duration of the liability portfolio than that of the asset portfolio means that the present value of the liability increases by a large amount than that of the asset as a result of the declined interest rate[11]. However, if life insures, observing the term structure, can perceive the possible decline tendency of the future interest rate, and if they increase ex ante the dollar duration in the asset side before the falling of the interest rate, the surplus loss from mismatching as the decline the interest rate can be reduced or avoided. So this gives them the incentive to adjust the duration ex-ante observing the sign of the future interest rate change. (The symmetric reasoning can be made for the case of the increasing of the interest rate.)

The empirical implication in Ozdagli and Wang (2019) also provide the motivation to explore of the relationship between the duration adjustment and the term factors that contain predictive

[10] Even if there are some perfectly matched life insures, which means the duration gap is zero. The declining interest rate would generate the duration gap (larger duration in the side of liabilities) immediately because of the difference in convexity.

[11] In the practice, such conceptual process corresponds to the situation: life insurers have to re-invest expired bonds at a lower yield in the environment of declining interest rates while contractural case outflows of insurance policies stay fixed, in which the capital is eroded as a result of reduced investment income.

information of the future interest rate rather than only the current level of rates. Because their testing result shows that the interest rate level alone does not significantly affect the duration adjustment, which is against the common sense that life insurers tend to lengthen their asset duration when the interest rate declines as the case study in Domanski et al. (2017).

Based on the literature about the term structure previously discussed, the future interest rate level is positively associated with the slope of the term structure and negatively associated with the curvature of the term structure. Observing these factors of the term structure, which implies the future change of the interest rate level, life insurers might adjust their interest rate risk exposure accordingly.

Hypothesis 2: As the increasing (decreasing) of the term spread, life insurers decrease (increase) the dollar duration in assets by trading bonds or/and interest rate derivatives.

4 Data and measurement

The primary data source is NAIC statutory annual report compiled by S&P global market intelligence (acquired SNL financial at 2015). The bond holding information is drawn from Schedule D which provide the detailed security-level holding. The derivative holding information is drawn from Schedule DB which is the holding data at the instrument-level. All insurers' characteristics used in this paper is also pull out from the same data platform, except one of financial constraint measures, A.M. Best financial strength. Here acknowledge that A.M. Best company generally shares financial strength ratings of U.S. life insurance companies for time period from year 2010 to year 2018.

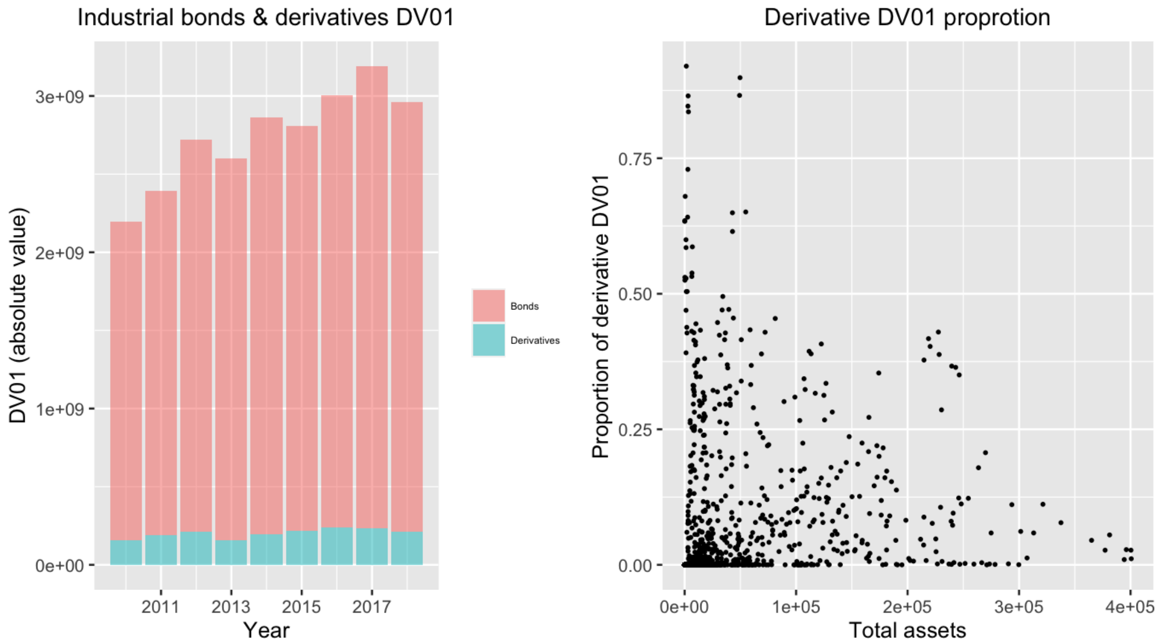
4.1 Duration measure of the bond portfolio

The interest rate can affect the duration of the bond portfolio through two channels. First, as in the duration formula, duration is a function of the interest rate, which means the interest rate changes the duration even holding the bond and derivative portfolios unchanged. (Specifically, the duration of bonds with coupon decreases with yield to maturity.) This is how the duration is defined. Second, the interest rate might also change the duration because insures might react to the interest rate change by restructuring bond portfolios, which is what the paper wants to test. So a duration measure required should be able to isolate the second channel from the first one. Common duration measures, such as Macaulay duration or modified duration, can't satisfy this requirement since they are a function of the interest rate.

A revised duration that are invariant to the change of the interest rate level and include all information of the cash flows of bonds. This measure is designed to capture the adjustment of

Figure 2: Duration exposure of bonds and derivatives

The derivative duration exposure illustrated in the both panels are the absolute value of $DV01$ as the $DV01$ of derivative could be negative. It is easier to use absolute value instead of original value to provide a meaningful comparison of duration exposure of bonds and derivatives. The combined $DV01$ in the right panel is the summation of the absolute $DV01$ of bonds and derivative as well. The unit of total assets in the right panel is million dollars. The dot in the right panel are year-insurer observations.



insurers' bond holding, so it incorporates the amount of coupon and principal and the frequency of coupon payment and maturity.

To suit this requirement, the duration is computed this way. For a bond, calculate its duration at different effective interest rate rates according to the duration formula (ex. modified duration). Then, take the average of the duration values at different interest rate rates. The average duration is invariant to the interest rate level but able to take into consideration all rest of information of bonds. See Appendix for the detail of computation.

4.2 Duration measure of interest rate derivatives

In Swap Manager function, Bloomberg provides the calculation of DV01 for interest rate floors, caps and swaptions contracts with almost all customized contract attributes such as notional value, strike price, effective and maturity date, floating index and payment frequency. The valuation setting also provide the option to choose the yield curve date that discounted rates are based on. Basically, with the swap manager function, DV01 at any given date for any interest rate derivative contract can be evaluated. Therefore, in order to obtain to DV01 for interest rate derivatives held by life insurers, it only needs to input the holding information of derivatives in the statutory report.

To obtain a measure of $DV01$ that only reflects the holding of derivatives not the interest rate level, it evaluates $DV01$ using a swap curve averaged over all swap curves at NAIC report dates. That is, the averaged swap curve is compose of swap rates that are the average value of rates with the same term on all swap curves.

The strike price of caps and floors are not able to be obtain from Schedule DB of the annual report because many insurers report the strike price and the floating rate together without specifying which is which. The strike price of these interest rate derivatives are, therefore, simplified as the swap rates implied by the average swap yield curve as well. In Schedule DB, the effective date of the derivative contract is not reported. It uses the report date as the effective date and the time difference between report date and the expiration date as the maturity of the contract. Other contact information that are specific for different types of interest rate derivatives are list in Appendix A.

The $DV01$ of caps can be exported directly from Bloomberg Terminal. Then, the $DV01$ of interest rate floors can be obtained from the put-call parity. That is, short a cap option and long a floor option with the same strike price and payment structure is equivalent to long a swap contract that pays the floating-rate and receive the fixed-rate equal to the strike price of the cap and the floor. Thus, the $DV01$ of long a floor are the result of the $DV01$ of the long position of a received-fixed swap minus a the $DV01$ of the short position of a cap.

Like swaps, caps and floors, Bloomberg also provides the calculation of $DV01$ for swaption contracts. However, it has to ignore the duration exposure of swaption here because the information to calculate $DV01$ is far from complete. Only partial of companies report the tenor of underlying swaps which has a linear relation with the value of $DV01$. A proximation of the tenor is not possible as the tenor could vary from 1 year up to 30 year. The reason that the impact of ignorance of swaption duration is negligible is that the notional exposure of swaptions is very limited. For the same reason it ignore the duration exposure of forwards, futures and other interest rate derivatives.

Figure 2 illustrates the comparison of duration exposure at the industrial level and the individual insurer level. At the industrial level as shown in the left panel of Figure, the dominant duration exposure exits in the bond portfolios and the derivative duration exposure is comparably very limited in all years of the sample period. However, for individual insurers the bond the duration exposure does not necessarily cluster in the bond portfolios as in the right panel. There are quite a few observations where derivative duration accounts for a large chunk of total combined duration exposure. Such case is common for small-size insurers while for the large insurers whose total assets are greater than $300,000$ million dollars the more than 87.5% of duration exposure still exists in bond holdings.

4.3 Measures of Interest rate movements

To measure the level of interest rates, two measures are derived from the yield curve. One is the simple average of a sequence of spot rates[12] on the treasury yield curve. The other level measure is the average of the same spot rates weighted by the holding information of bonds. For instance, the weight of 10-year spot rate is determined by the proportion of 10-year bonds held by the life insurance industry within the sample period. The measure of the term spread is using the difference between the 10-year and the 3-month treasury rate for the short end of the yield curve and the difference between the 30-year and 10-year for the long end of yield curve. The 10-year and 2-year term spread is also computed to compared with the 10-year and 3-month term spread as another common term spread for the short end of yield curve.

Appendix Table C.4 shows the correlation matrix of the interest rate factors. It is designated to exclude the possibility of collinearity. Namely, the measures of the interest rate level might be highly correlated with the measures of the term spread. From the table, the weighted level of interest rate is less linearly correlated with the measures of the term spread, which shows that it is worthy testing on the weighed level in order to assure of the valid estimation of the effect of the interest rates factors.

4.4 Other cross-sectional attributes and their measures

The duration for the liability portfolio is an important variable to determine the duration matching because it affect the duration gap directly. However, it have been a difficulty to calculate duration for the liability portfolio of insurers because of the lack of relevant product information. Kirti (2017) simply assumes average modified duration of these liabilities is 15 years and Domanski et al (2017) consider roughly the aggregate cash flow of the liability portfolio to be a deterministic value with a fixed decay rate. These proxies are far from the accurate measurement of the liability duration. Following the idea of the mismatch measure first suggested by Flannery and James (1984) and then applied by Colquitt and Hoyt (1997) into the life insurance industry. This paper use the amount of long-term liabilities to proxize the interest rate risk exposure in the liability. Long-term liabilities here include individual and group annuity reserves, ordinary life insurance reserves and supplementary contract reserves. Additionally, leverage is also used as another measure of interest rate risk exposure in the liability. Computed as the liability value relative to that of the surplus, the leverage represents the amount of liability per unit of the surplus. The larger the leverage is, the higher interest rate risk exposure in the liability it can be conditional on the surplus.

[12]The spot rates include those with maturities being 1-month, 3-month, 6-month, 1-year, 2-year, 5-year, 10-year, 20-year and 30-year.

Regulatory constraint is measured by the company action level risk based capital (RBC) ratio. Then, use dummy variables to indicate insurers as four categories according to their RBC ratio percentiles. The surcharge of the interest rate risk in the RBC ratio reflect that the regulatory requirement of the capital sufficiency (the numerator of the RBC ratio formula) relative to the risk-taking (the denominator, RBC). It is consistent with the economic incentive to hedge the interest rate risk, which is conceptualized in the paper as the exposure of the interest rate risk and the value of surplus. Although the RBC ratio requirement is not strict in the sense that it is far from being binding for many insurers and the adjustment frequency required is not very high, it does reflects the necessity of duration-mating on the economic basis. The concern of using RBC ratio as an attribute of life insurers is the endogeneity issue, the reversal casualty. The extent of being regulatorily constrained indeed affects the duration-matching while at the same time the duration adjustment through structuring bond portfolio affects the RBC and, therefore, the RBC ratio as well. In Section 6, financial strength ratings evaluated by A.M. Best company is employed to examine the role that financial constraint plays in duration matching.

Table 1: Summary statistics

The sample period of summary statistics is from 2004 to 2018. Panel A reports the summary statistics for the observations of all life insurers in the time period. "Combined asset duration" is the dollar duration in the bond portfolio plus the dollar duration of interest rate derivatives, the unit of which is dollar per basis point. The unit of "total assets" is thousand dollars. "Long-term liability proportion" is measured by the value of long-term liabilities over that of total liabilities. Panel B reports summary statistics for annul treasury yields, the units of which is percentage. "Interest rate level" is the simple average of treasury yields with selected maturities. "Interest rate level (weighted)" is the average weighted by the holding information of bonds. "Term spread (10Y-3M)" is the difference between the 10-year treasury yield and the 3-month treasury yield.

Statistic	N	Mean	St. Dev.	25%	Median	75%
Panel A: Life Insurer Observations						
Combined asset duration	9,107	4,227,932	16,742,319	22,572	228,086	1,609,559
Total assets	9,107	7,351,011	28,095,211	46,999	356,236	2,701,602
Long-term liability proportion	9,107	0.512	0.328	0.201	0.569	0.819
CAL RBC ratio	9,107	1,110.168	3,420.612	336.605	476.720	763.750
Panel B: Interest Rates of treasury						
Interest rate level	3,753	2.213	1.259	1.224	1.711	2.837
Interest rate level (weigted)	3,753	2.693	1.137	1.797	2.355	3.607
Term spread (10Y-3M)	3,750	1.844	1.051	1.160	1.935	2.610
Term spread (20Y-10Y)	3,753	0.537	0.258	0.320	0.540	0.760
Term spread (30Y-20Y)	3,227	0.170	0.189	0.020	0.240	0.310
Term spread (30Y-10Y)	3,753	0.684	0.348	0.400	0.740	0.940

5 Incentives of duration matching

This section is to construct a static industrial asset-liability portfolio of life insurers. It is used as a representative asset-liability portfolio in the life industry. With the representative portfolio, it can then derive the corresponding change in the duration gap with the change of interest rates. The goal is to justify the incentive of insurers to match duration with the interest rate fluctuation. For instance, as the interest rate decreases, the duration gap of the representative portfolio would get enlarged, which would incentivize life insurers to lengthen the asset duration.

5.1 Simulate a representative asset-product portfolio

Liability portfolio The representative liability portfolio is constructed using the industrial aggregate information of assets and liabilities. The asset portfolio is aggregated from long-term bond holding in Schedule D. The information of the liability by types of products is difficult to obtain as the categorization of insurance and annuity products is very rough in the statutory report. To determines a proximate value proportion of products of different types, several data sources is used. The proportion of life insurance and annuities of the industry is in reference to the reserve value of them in ACOLI (2018). Within life insurance products, the fact amount of different insurance products calculated in LIMRA and SOA (2019) is used to determine their value proportion. The value proportion of term life insurance by terms is collected from SOA and LIMRA (2018). The annuity proportion by types is from IRI (2015). Appendix Figure C.2 summarizes the age profiles and the calculation of risk exposure.

To project cash flow of insurance policies over the time, the exposure information cross the age of policyholders for each type of insurance policies is also needed. Referring to survey reports, Shaughnessy and Tewksbury (2019) and Drinkwater et al. (2018) carried out by SOA and LIMRA, the exposure information falling into different age cohort is summarized in Appendix Table C.1.

Proportion of the asset and the liability exposure Long-term bonds and liabilities exits both in the general account and the separate account[13]. Only the aggregate value in the general account is used as the gross value of the representative asset-liability portfolio. The rationale is that the products in the separate account are mostly investment-linked contracts whose payoff depends on the performance of underlying assets which are designated separate account assets. This means that theoretical there should be no interest rate risk existing in the separate account

[13]The asset risk exposure predominantly exists in the general account. As of 2014, there are 144 of 688 operating life insurers filling separate accounts statement with NAIC. And 90 of them have bond holding in their separate accounts. The aggregate bond holding in the separate accounts only account for 6.1% of bond holding in the general accounts.

as the payoff of policies in the separate account is consistent with the investment income of general account assets. The total face value of long-term bonds reported in Schedule D Part 1A of the general account is $5,370,201,984$ \$000s and the total value of life insurance and annuity reserve are $2,031,864,712$ \$000s and $2,731,094,781$ \$000s, respectively[14].

5.2 Project cash flows of the asset-liability portfolio

In order to study how the duration gap changes with interest rate movement, the cash flows of the representative asset-liability portfolio need to be projected across time. The asset-liability portfolio constructed to calculate the duration gap is the industrial portfolio of the year end of 2014. The representative portfolio uses the information of security-level bond holding and insurer-level of product reserve of general accounts. Appendix Table C.3 lists the value of bonds and life insurance and annuity reserve in the two accounts which are the primary interest rate rate risk exposure on the balance-sheet.

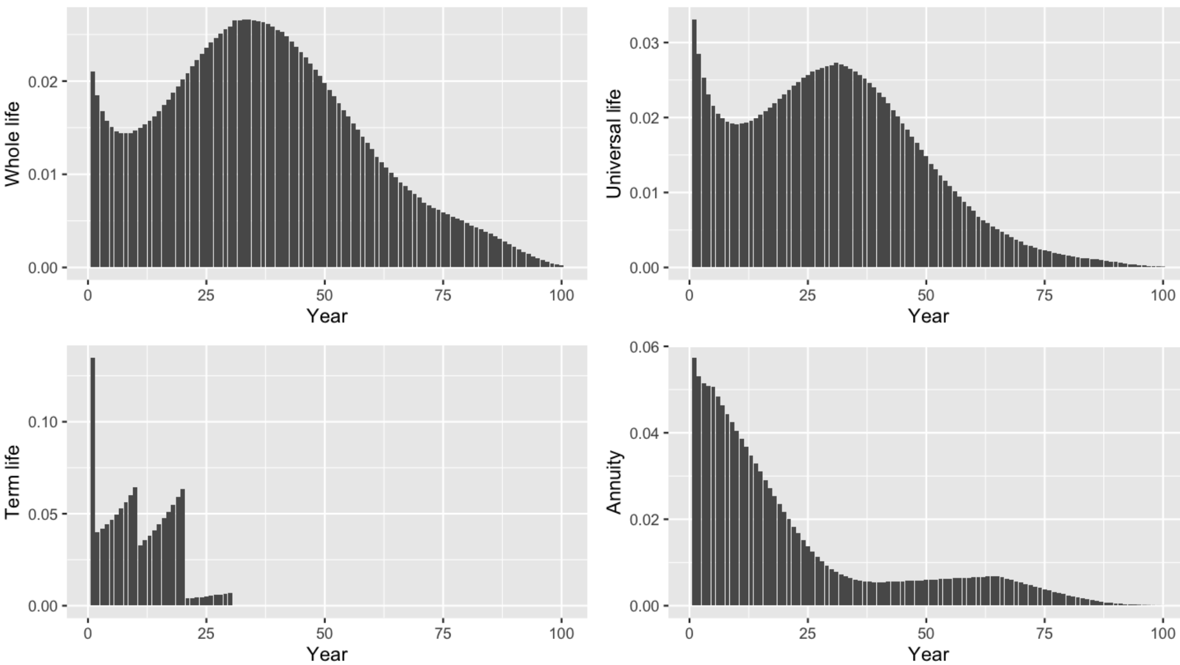
Cash flows of the asset portfolio The interest rate risk exposure in the asset portfolio dominantly exists in bond holding. Using security-level holding data from investment detail (For the general account, the detailed holding information is reported in Schedule D Part 1A.), it projects the cash flows of bonds, coupon payment of each term and principal when they expire. Since the goal is to build a represent portfolio for the life industry, it aggregate cash flows of all bond holding reported by all operating life insurers in 2014. The coupon is standardized as annual payments and the all coupon and expiring principal payment are considered to be paid at the beginning / ending of each year closest to their actual pay-date.

Cash flows of the liability portfolio The exposure of liabilities by types of products and by age cohorts has been obtained as in Table C.2 and Table C.1. Within each age cohort, assume the exposure is evenly distributed among the policyholders with different ages. After determining the cash flow of a single insurance police for all types and all ages of policyholders, it sums up cash flows of all individual polices to derive the aggregate cash flow of the liability portfolio.

I simplifies the payment of cash flows of different life insurance industry products into two primary types. For life insurance products, the cash flow of them is considered as a lump-sum payment of death benefit at death, which is applicable to life insurance including term life, whole life and universal life insurance. The cash flow of annuities is simplified as periodical

[14] The detailed value of assets and liabilities assigned in the general account and the separate account is listed in Table C.3 in Appendix.

Figure 3: Cash flows of life industry products



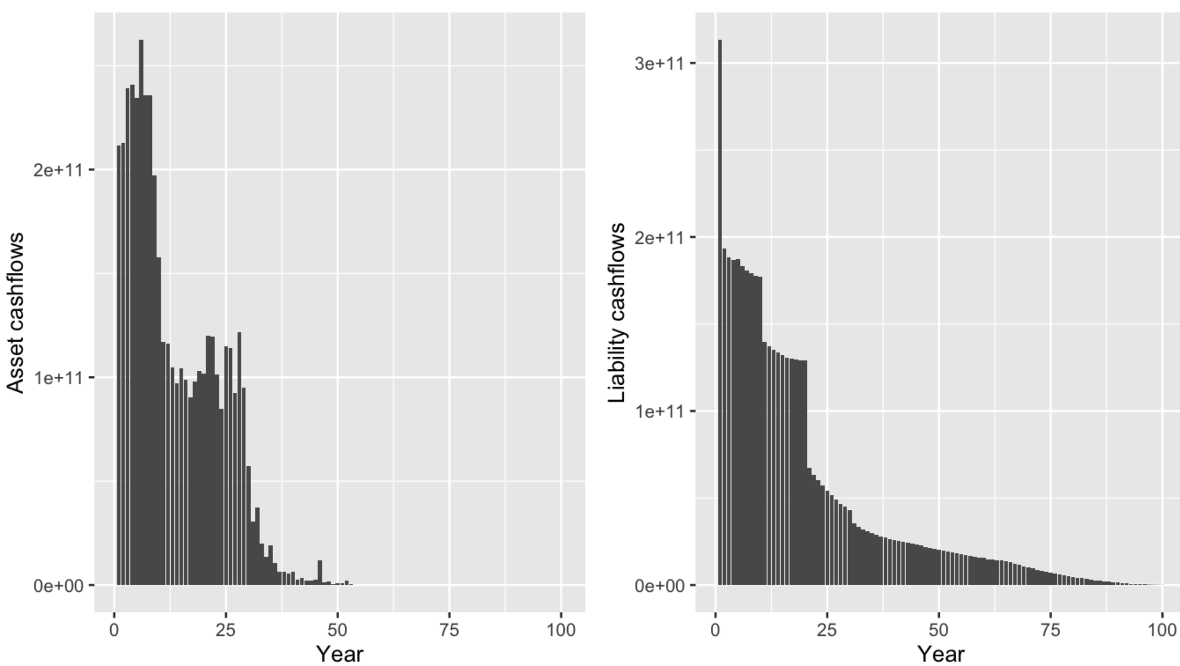
Note: the value of y-axis is the relative value. The gross exposure of each type of products is normalized to unit 1.

payments. The premium of annuity policy is annualized payments until death or the expiration of the contract applicable to annuities.

The death and living benefit payments is determined by discounting the value of polices by the mortality rate. The mortality rate references to United States national life tables in 2015 (Arias and Xu, 2018). As for life insurance polices, it use age 100 as the terminal age, which means the death benefit would be paid to police holders when they reach 100. As for annuities, it assumes that the living benefit is paid until age 100 even if policyholders can live beyond 100 years old. More specifically, it assumes a unified discount rate when insurers set the death and living benefits. The benefit payments is derived based on the principle of pricing: actuarial value of the benefit payment being equal to premium. For universal and whole life insurance, it assumes half of premium or reserve is set to pay death benefits (the other half is the saving component which is paid upon surrender). Therefore, for those types of insurance contracts only 50% of the amount of gross premium or reserve is used as their exposure measure. The average annualization age of annuities is assumed to be 65. That is, the first payment of living benefit is paid once policyholders reach age 65.

It is worthy mentioning that withdrawal and surrender activities of policyholders are not taken into considerations when calculating interest rate risk exposure. First, it is because that withdrawal and surrender activities does not affect the calculation of duration by definition. Withdrawal /surrender is policyholder's behavior that would change the structure of payment cash-flow of insurers. Nevertheless, the interest rate risk is about the present value change of a scheduled cash-flow caused by the interest rate change. The change in payment cash-flows caused by contract-holder behavior (such as lapses, withdrawals, transfers, recurring deposits, benefit utilization, option election, etc) are unscheduled. In this sense, surrender / withdrawal cannot be incorporated in the concept of duration. Secondly, withdrawal /surrender should not impose extra loss on insurers related to the interest rate. Because the Withdrawal /surrender policy is designed more friendly to insurers than policyholders. Although, withdrawal/ surrender behavior caused by the change in interest rate can affect the value of cash-flows, such policyholders' behavior is difficult to predict accurately. In practice, in the absence of relevant and fully credible empirical data, the actuary company set behavior assumptions and the variance in behavior assumptions can significantly affect the results (NAIC VM, 2020). Such difficulty in predicting policyholders' behavior makes it impossible to incorporate the behavioral reasons (rather than the term of payments) into the concept of duration.

Figure 4: Asset and liability cash-flows



The projection of the payment cash flow of different insurance polices is shown in Figure.(3). The cash flows of whole life and universal life insurance policies have the similar pattern with the summit value of the cash-flow around year 25. The distribution exhibits a relative heavy tail. In contrast, the exposure of annuities heavily distributed among the early years, from year

1 to year 10, proximately. The non-smooth cash-flow shape of term insurance policy is due to the several fixed-term of contracts. In the sample deriving this figure, term insurance are composite of yearly renew term, 10-year level premium term, 20-year level premium term and 30-year level premium term. The spike in the first year is explained by the exposure of policies with yearly renew term.

Aggregating the cash flow of individual policies, the projection of cash flows of the industrial portfolios for assets and liability is as Figure 4. The spike of the liability cash-flow in the year is due to the exposure of yearly renew term insurance. The liability cash-flow has a heavier tail than the asset cash-flow. This is because the maximal maturity of majority treasury bonds are 30-year while the future life of policyholders can up to much more than 30 years. The longer and heavier tail of the cash flows of liabilities relative to the ones of assets can explain the different duration and convexity nature of the asset and the liability portfolio. That is, both the duration and convexity of the liability portfolio is larger than those of the liability portfolio.

5.3 The incentives of duration adjustment

Interest rate risk exposure exists in both the general account and the separate account. To figure out the duration gap between the asset and the liability portfolio, it is necessary to take into consideration the risk exposure in both accounts.

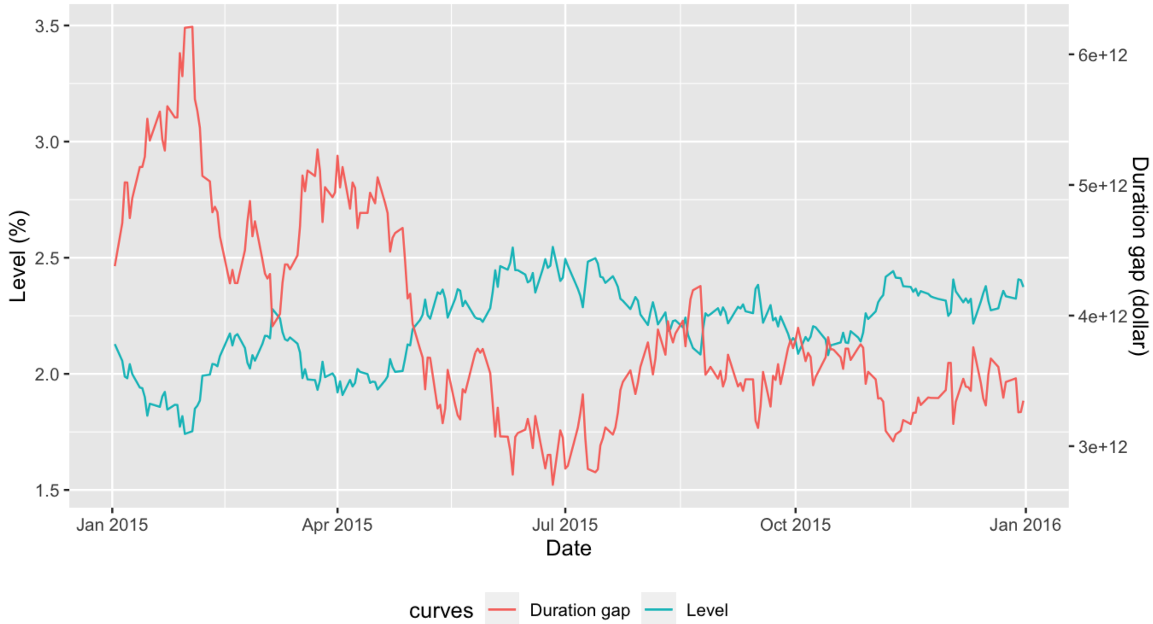
The discount rates used to calculate duration are treasure yields. The time window investigated is from 2010 and 2018, during which periods it collects daily yields for 1-year, 2-year, 3-year, 5-year, 7-year, 10-year, 20-year and 30-year treasure notes or bonds.

To obtain the entire yield curve (yearly) from one-year to thirty-year, it first calculates the forward rates based on the internal interest rates of these treasure bonds. The implied forward rates in-between two types of treasure bonds that have the closest term is assumed to be equal. (Give a numeric example here.) Using these yearly forward rates from year one to year 30, it, then, derivates all internal interest rates corresponding to all 30 year maturities. Appendix Figure C.2 illustrates the interpolated yield curves.

Duration gap and term structure factors This section is devoted to justify the incentive of life insurers to adjust their duration reacting to the fluctuation in the interest rate. Specifically, it aims to show that if the level of the interest rate declines, the duration gap would get enlarged. Also, the reduced the slope of the term structure predicting the decline of the future interest rate is another signal that would enlarge the duration gap. Therefore, the worsened mismatching would incentivize the adjustment of the duration.

The duration measure employed is the effective duration where the discount rate is used the internal rate of each year interpolated from treasury yield curves. Since the maximal maturity

Figure 5: The evolution of the duration gap and the interest rate level during year 2015



of treasury yield curve is only up to 30 years, for that cash flows that are beyond 30 years, it assumes the discount rate is equal to the yield of 30-year treasury bonds. The level of the term structure is computed as the average of the internal interest rates of treasury bonds from one-year to 30-year. The slope of the term structure is measured by the difference between 10-year and 3-month treasury bonds.

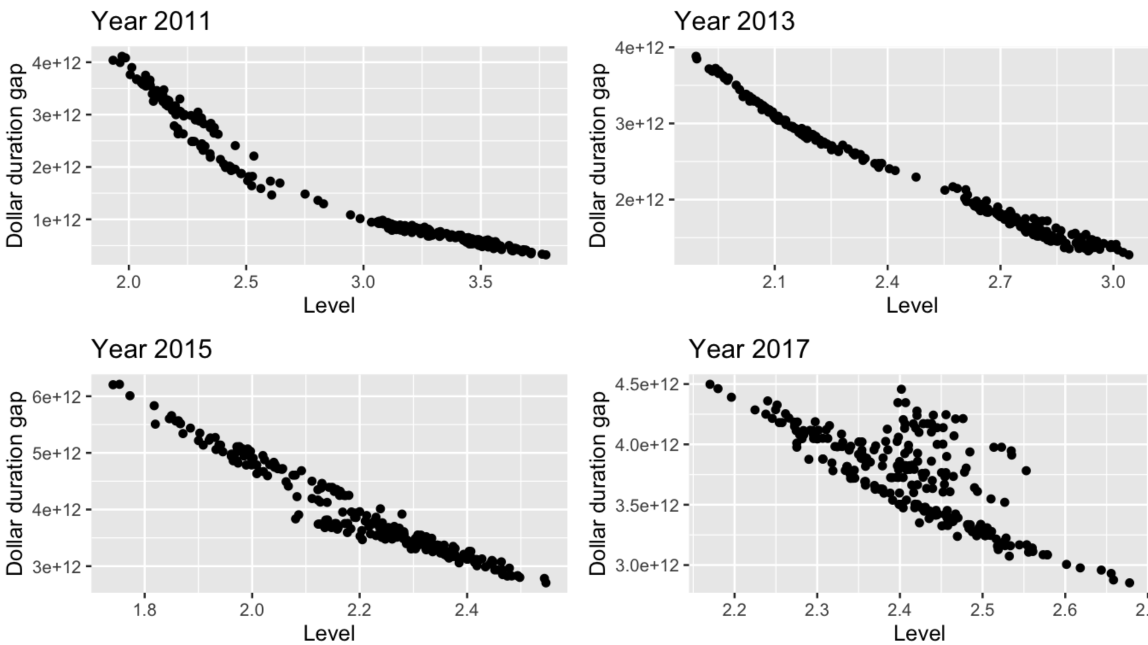
The first conjecture specifies the relation of the duration gap and the interest rate level that motivates matching behavior. In particular, the reduced level of interest rates enlarges the dollar duration gap of a typical asset-liability portfolio of life insurers, which incentives life insurers to close the gap.

Conjecture 1. *The dollar duration gap of a representative asset-liability portfolio of life insurers is negatively associated with the level of interest rates.*

Figure 5 illustrates the change of the duration gap of the representative portfolio of year-end 2014 with the evolution of the interest rate level of year 2015. It shows the clear negative association between the interest rate level and the dollar duration gap. The reason of the negative pattern is rooted in the fact that the cash flow of the liability portfolio has a much longer tail as show in the Figure 4. Therefore, the convexity of liability duration is larger than that of asset duration, which means as the interest rate decreases, the liability duration increases by a large amount that the asset duration.

Figure 6 plots the daily levels of the term structure against the duration gap of the asset-liability portfolio during year 2011, 2013, 2015 and 2017. As presented in the figure, there are negative correlation between the level and the duration gap in all the four panels. For one value of the interest rate level it could correspond to multiple values of the duration gap, especially, as in the right-bottom panel. The reason is that each of the level could be derived from different yield curves from which different values of duration gap can be evaluated.

Figure 6: The interest rate level and the dollar duration gap



The second conjecture is employed to reason why life insurers would adjust duration with the change in the slope of the term structure. It proposes that the reduced (increasing) slope would enlarge (close) the future duration gap so that motivates adjustment behavior.

Conjecture 2. *Controlling the interest rate level, the future dollar duration gap is negatively associated with the slope of the term structure.*

The necessity for controlling the interest rate level is due to the fact that the dollar duration gap is (negatively) correlated to the interest rate as shown in the conjecture 1. The current interest rate level would still have an impact on the future duration gap as the sudden change of the yield curve is very uncommon. Therefore, in the follow regression in Table 2 it controlling the current the interest rate level investigates the correlation between the current slope value and the future dollar duration gap.

The main information that this table conveys is the negative association between the slope and the future duration gap. The negative sign of slope coefficients persists from 2 weeks ahead up to 9 months ahead, as in columns from (1) to (9). The negative correlation disappears after one year, as in column (6), (7) and (8). If the duration gap becomes worse, the surplus value would be suppressed without duration-matching. Economically, the surplus loss is due to the fact that the expired investment (mainly, bonds) would receive a lower return after reinvestment in general while the liabilities with longer terms still pay out the same contractual yield to policyholders. That is, the investment income would be not able to cover the payment at the liability side as well as before because of the reinvestment risk, which causes the gradual erosion of the surplus value. According to the first five columns in Table 2, a decreasing in the slope would subject life insurers to a constant surplus loss for the next night months if they do not rematching the duration. Such surplus loss would not stop until next year as indicated in column (6).

Table 2: The slope of the term structure and the future duration gap

	Dependent variable: future dollar duration gap (in trillion)							
	2-week after	1-month after	3-month after	6-month after	9-month after	1-year after	1.5-year after	2-year after
	OLS	*OLS*	*OLS*	*OLS*	*OLS*	*OLS*	*OLS*	*OLS*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
level	-1.588^{***}	-1.521^{***}	-1.414^{***}	-1.186^{***}	-1.027^{***}	-1.348^{***}	-1.489^{***}	-2.220^{***}
	(0.029)	(0.034)	(0.043)	(0.058)	(0.071)	(0.108)	(0.137)	(0.219)
slope (10y&3m)	-0.747^{***}	-0.711^{***}	-0.614^{***}	-0.405^{***}	-0.203^{***}	0.635^{***}	1.418^{***}	2.160^{***}
	(0.021)	(0.024)	(0.031)	(0.043)	(0.053)	(0.086)	(0.118)	(0.197)
Constant	8.496^{***}	8.265^{***}	7.821^{***}	6.861^{***}	6.082^{***}	5.169^{***}	3.913^{***}	4.048^{***}
	(0.060)	(0.070)	(0.084)	(0.107)	(0.120)	(0.136)	(0.126)	(0.139)
Observations	2,241	2,230	2,209	2,168	2,126	2,001	1,876	1,751
R^2	0.820	0.760	0.644	0.417	0.256	0.100	0.072	0.069
Adjusted R^2	0.820	0.760	0.644	0.417	0.255	0.099	0.071	0.068
Residual Std. Error	0.578 (df = 2238)	0.664 (df = 2227)	0.799 (df = 2206)	0.995 (df = 2165)	1.106 (df = 2123)	1.166 (df = 1998)	1.029 (df = 1873)	1.010 (df = 1748)
F Statistic	$5,109.420^{***}$ (df = 2; 2238)	$3,522.405^{***}$ (df = 2; 2227)	$1,994.872^{***}$ (df = 2; 2206)	775.602^{***} (df = 2; 2165)	365.103^{***} (df = 2; 2123)	111.036^{***} (df = 2; 1998)	72.829^{***} (df = 2; 1873)	64.623^{***} (df = 2; 1748)
Note:								*p<0.1; **p<0.05; ***p<0.01

The magnitude of the coefficient of the slope is stronger for the duration gap of the nearer future. It means the impact of the slope on the duration gap gets weaker and weaker over the time. The current interest rate level is negatively related to the future duration gap, which is as expected. The reasoning is: the high (or low) current interest rate level implies the future interest rate level is more likely to be high (or low) as the sudden change of the yield curve is very rear. The high (or low) future interest rate level leads to the low (or high) duration gap, the negative relation implied from which has been verified from Conjecture 1.

6 Stylized facts of matching behavior

This section verifies the stylized facts derived from the hypotheses between duration adjustment in assets and interest rate movements. The first challenge is to compute a reasonably accurate measure of duration adjustment. Kirti (2017) and Ozdagli and Wang (2019) uses the duration gap between the asset and the liability portfolio, which is most natural measure of duration adjustment. However, the computation of the measure is very rough for the lack of insurance product information while the asset duration can be precisely calculated. As pointed out by Kirti (2017) and Ozdagli and Wang (2019), their calculation of the duration at the liability side is very rough. That is, as the adjustment variable the duration gap can only be vaguely measured because of the lack of information from the liability side. To get around the issue, I instead use duration exposure in assets (including derivatives) as the independent variable to measure the duration adjustment and control the liability risk exposure using the proportion of long-term liabilities at the right-hand-side of regression specifications, for instance, as in Equation 1. Therefore, the imprecise measurement of liability risk exposure would not distort the precision of asset duration. The implement of duration matching implied by this approach is more aligned with the reality for two reasons. First, life insurance are primarily liability-driven business[15], which means assets are chosen to match with liabilities in a risk efficient manner (Gilbert, 2016). Secondly, even with complete information of their liability portfolios, it is still challenge for actuaries to precisely calculate liability duration because of the complicity of various insurance products. Not like asset duration, there seems no unified rule to calculate liability duration.

The using of derivative is also considered to study the duration adjustment behavior of life insurers. As shown in 2, there are quite a few insurers holding substantial duration exposure in their derivative portfolios. It is reasonable to incorporate derivative duration in studying the duration matching, especially for those large holders of interest rate derivatives. Therefore, the asset duration measure used in this paper is the asset duration combined with derivatives, the total duration in the bond and the interest rate derivative portfolio.

Additionally, to study the portfolio adjustment behavior, namely, how life insurers actively balancing their portfolios out of considerations of matching duration, I follow the approach used by Ozdagli and Wang (2019), where they identify such active adjustment behavior by isolating the duration change cause the active adjustment from duration change caused by in interest rates. Next subsections will test the stylized facts of duration matching for both overall duration adjustment and active duration adjustment.

6.1 Overall duration adjustment

Equation 1 gives the specification of overall duration adjustment with interest rate movements.

$$d_{it} = \alpha_i + \beta_1 \mathbb{E}[\text{level}]_{[t-1:t]} + \beta_2 \mathbb{E}[\text{term spread}]_{[t-1:t]} + \Gamma X_{it} + \epsilon_{it}, \tag{1}$$

[15] See Berends et. al. (2014) and Bragt and Kort (2010).

Table 3: Overall duration adjustment and interest rate movements

This table reports the regression result of overall duration adjustment. The sample period is from 2004 to 2018. For the time period from 2004 to 2009, as lack of derivative data to compute its duration exposure, only non-derivative users are included in the sample. Non-derivative users are determined as those who are below the top 5% percentile in terms of the absolute book value of derivatives. Column (1) to (4) uses fixed effect model and column (5) uses the OLS model. The dependent variable "average duration" is defined as the sum of bonds and interest rate derivatives duration divided by total assets. Long-term liability proportion is the percentage of long-term reserves in total liabilities. The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

	Dependent variable: Average duration				
	(1)	(2)	(3)	(4)	(5)
Level	-0.186^{***}	-0.334^{***}	-0.347^{***}	-0.316^{***}	-0.421^{***}
	(0.025)	(0.041)	(0.051)	(0.049)	(0.047)
Term spread (10Y-3M)		-0.270^{***}	-0.256^{***}		-0.268^{***}
		(0.039)	(0.033)		(0.065)
Term spread (30Y-10Y)			-0.098	-0.611^{***}	-0.395
			(0.142)	(0.158)	(0.242)
Long-term liability proportion	1.875^{***}	1.968^{***}	1.970^{***}	1.918^{***}	3.377^{***}
	(0.433)	(0.436)	(0.436)	(0.434)	(0.111)
Log[total assets] (in thousand)	0.605^{***}	0.504^{***}	0.499^{***}	0.542^{***}	0.185^{***}
	(0.134)	(0.136)	(0.138)	(0.137)	(0.014)
Dummy: RBC ratio < 10%	-0.137	-0.131	-0.131	-0.135	0.187
	(0.136)	(0.137)	(0.137)	(0.136)	(0.122)
Constant					4.341^{***}
					(0.323)
Fixed effects	*Firm*	*Firm*	*Firm*	*Firm*	–
Observations	9,107	9,107	9,107	9,107	9,107
R^2	0.806	0.808	0.808	0.807	0.116
Adjusted R^2	0.786	0.789	0.789	0.787	0.116
Residual Std. Error	1.717	1.707	1.708	1.714	3.492
Note:					*p<0.1; **p<0.05; ***p<0.01

where d_{it} is the average duration of the asset portfolio defined as $\frac{D_{it}}{\text{Asset}_{it}}$. D_{it} indicates the sum of Macaulay duration of bond portfolios and interest-rate derivatives divided by the value of total assets. $\mathbb{E}[\text{level}]_{[t-1:t]}$ and $\mathbb{E}[\text{term spread}]_{[t-1:t]}$ are the average interest rate level and term spread from $t-1$ to t, respectively. X denotes attributes of insurers including total assets, the financial constraint and the interest rate risk exposure in liabilities measured by the proportion of long-term liabilities in total liabilities. The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

Table 3 show that U.S. life insurer increase asset duration on average 0.3 year reacting to the 1% decreasing of the interest rate level during the period 2004-2018. Both the change in the short-end and the long-end of the term spread (10Y-3M term spread and 30Y-10Y term spread, respectively) significantly affect the duration adjustment. The change in the long-term liability proportion is positively significant, which means that the more risk exposure in the liability, the more dollar duration change relative to the asset increases because of duration-matching. The size effect measured by the logarithm value of total asset is positively significant, which means the extent of duration adjustment is larger for the insurers with more assets. The most constrained insurers, those whose RBC ratios fall below 10% percentile, appear to bear more interest rate risk, indicated by the negative sign of the dummy variable of low RBC ratios. But the coefficients are not statistically significant.

Appendix Table C.5 compares the duration adjustment across derivative users and non-derivative users. The sign and significance of the coefficients keep consistent cross-sectionally. Derivative derivative usurers react more intensively towards interest rate fluctuation than non-derivative users. This suggests derivative hedging against hedge interest rate risk could be more intensive than hedging by structuring bond portfolios.

Appendix Table C.9 provides the robustness test in terms of alternative duration measures. Columns (1), (2) and (3) use the simple average of spot rates on the treasury yield curve as the measure of the interest rate level. Columns (4), (5) and (6) use the average of sport rates weighted by the aggregate holding information of bonds as the measure of the interest rate level. All coefficients of interest rate factors variables indicate the expected effects on the average duration consistent with the hypothesis. Moreover, the term spread of the long-end of yield curve more substantially impacts the asset duration than that of the short-term.

6.2 Active portfolio adjustment

In practice, there are three approaches to actively adjust the duration of the asset portfolio, balancing current bond portfolios, trading interest rate derivatives and increasing bond holding using external funding from issuing debt or equity or the capital transferring from other affiliates. It is of interest to investigate how these aspect operations of life insurers react to interest rate movement. Although the result in Table 3 verifies the hypothesized association between interest rate movements and duration adjustment, it is not able to show that such duration adjustment comes from the active portfolio (including trading bonds and derivatives) structuring, because the portfolio duration is also affects the change in interest rates other than portfolio structuring.

Specifically, as in the duration formula, duration is a function of the interest rate, which means the interest rate changes the duration even holding the bond and derivative portfolios unchanged. (Specifically, the duration of bonds with coupon decreases with yield to maturity.)

This is how the duration is defined. Second, the interest rate might also change the duration because insures might react to the interest rate change by restructuring bond portfolios, which is what the paper wants to test. So a duration measure required should be able to isolate the second channel from the first one. Common duration measures, such as Macaulay duration or modified duration, can't satisfy this requirement since they are a function of the interest rate. To overcome the difficulty, this paper employs the duration measure of active duration adjustment proposed by Ozdagli and Wang (2019) and test whether the hypothesized duration matching pattern is indeed driven by portfolio structuring. The active duration measure is defined as

$$AD_t = D_t - LD_{t-1}(t), \tag{2}$$

where D_t is the combined asset dollar duration at time t. $LD_{t-1}(t)$ represents the dollar duration evaluated at time t for the legacy asset of time $t-1$. It is the hypothesized duration of the asset portfolio of time $t-1$ when the time moves to time t. So the interest rates used to evaluate the hypothesized duration is the interest rates of time t.

The basic specification of active duration adjustment is

$$Ad_{it} = \beta_1 \Delta \mathbb{E}[\text{level}]_{[t-1:t]} + \beta_2 \Delta \mathbb{E}[\text{term spread}]_{[t-1:t]} + \Gamma \Delta X_{it} + \epsilon_{it}, \tag{3}$$

where Ad_{it} is the average active duration defined as active duration divided by total assets, $\frac{AD_{it}}{V(\text{Asset})_{it}}$. $\mathbb{E}[\text{level}]_{[t-1:t]}$ and $\mathbb{E}[\text{term spread}]_{[t-1:t]}$ are the average interest rate level and term spread from $t-1$ to t, respectively. X denotes attributes of insurers including total assets, the financial constraint and the interest rate risk exposure in liabilities measured by the proportion of long-term liabilities in total liabilities. The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

Table 4 tests the association of active duration adjustment and the interest rate factors, parallel to the analysis regarding overall duration adjustment in Table 3. The negatively significant signs of the interest rate level and the term spread implies that life insurers indeed active structure portfolios (bonds and/or interest rate derivatives) with the movements of interest rates. Specifically, the average of asset duration increases around 0.1 year with 1% decreasing of the interest rate level, and increase around 0.5 year with 1% decreasing of the 30Y-10Y term spread. The 10Y-3M term spread also has the negative impact on the asset duration, although the average effect is much less than the term spread of the long-end of yield curve, the 30Y-10Y term spread. Columns (1) and (2) use the simple average of spot rates on the treasury yield curve as the measure of the interest rate level. For robustness, Columns (3), (4) and (5) use the average of sport rates weighted by the aggregate holding information of bonds as the measure of the interest rate level. Table 5 compares the cross-sectional difference between derivative users and non-derivative users, which confirms the finding of duration adjustment in Appendix Table C.5 that the asset duration of derivative users responds more intensively to interest rate movements. This may suggest using interest rate derivative can help insurers better match duration.

Table 4: Active duration adjustment: Interest rate movements

The sample period is from 2010 to 2018. For the time period from 2004 to 2009, as lack of derivative data to compute its duration exposure, only non-derivative users are included in the sample. Non-derivative users are determined as those who are below the top 5% percentile in terms of the absolute book value of derivatives. The dependent variable is the active duration adjustment measured by active duration (defined in Equation 2) divided by total assets. Covariant "Level (simple average)" is the simple average of a sequence of spot rates on the treasury yield curve. Covariant "Level (weighted average)" is the average of the same spot rates weighted by the holding information of bonds with the corresponding maturity. The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

	Dependent variable: Active duration adjustment							
	Interest rate level				Weighted interest rate level			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ Level	−0.019	−0.074**	−0.131***	−0.127***				
	(0.025)	(0.031)	(0.037)	(0.031)				
Δ Level (weighted average)					−0.012	−0.127***	−0.128***	−0.129***
					(0.028)	(0.041)	(0.041)	(0.035)
Δ Term spread (10Y-3M)	−0.073***		−0.070***	−0.073***	−0.063***		−0.026	−0.030*
	(0.024)		(0.024)	(0.021)	(0.018)		(0.020)	(0.018)
Δ Term spread (30Y-10Y)		−0.496***	−0.486***	−0.464***		−0.520***	−0.450***	−0.440***
		(0.115)	(0.115)	(0.090)		(0.102)	(0.116)	(0.091)
Δ Long-term liability proportion	0.798***	0.773***	0.773***	0.762***	0.799***	0.769***	0.774***	0.763***
	(0.164)	(0.164)	(0.164)	(0.294)	(0.164)	(0.164)	(0.164)	(0.294)
Δ Log[total assets] (in thousand)	1.925***	1.931***	1.932***	1.618***	1.924***	1.932***	1.931***	1.617***
	(0.058)	(0.058)	(0.058)	(0.134)	(0.058)	(0.058)	(0.058)	(0.134)
Dummy: RBC ratio < 10%	−0.087**	−0.087**	−0.087**	0.007	−0.087**	−0.087**	−0.087**	0.008
	(0.043)	(0.043)	(0.043)	(0.070)	(0.043)	(0.043)	(0.043)	(0.070)
Constant	0.575***	0.564***	0.553***		0.576***	0.555***	0.555***	
	(0.014)	(0.015)	(0.015)		(0.015)	(0.016)	(0.016)	
Fixed effects	–	–	–	*Firm*	–	–	–	*Firm*
Observations	8,194	8,194	8,194	8,194	8,194	8,194	8,194	8,194
R^2	0.122	0.123	0.124	0.264	0.122	0.124	0.124	0.263
Adjusted R^2	0.122	0.123	0.124	0.183	0.122	0.123	0.123	0.183
Residual Std. Error	1.183	1.182	1.182	1.141	1.183	1.182	1.182	1.141

Note: *p<0.1; **p<0.05; ***p<0.01

Apart from testing the impact of interest rates on matching behavior, the role of the financial constraint, measured by RBC ratio is also investigated. From Table 3 and Table 4, the dummy variable indicating the life insurers with low RBC ratios, so that most constrained, generally negatively affect the asset duration. It suggests that most constrained life insurers would have a worse matching so that expose themselves to larger interest rate risk. The finding here is consistent with Rampini et al. (2019) in that poorly capitalized financial institutions hedge less against interest rate risk and foreign exchange risk. The negative effect of financial constrained hold cross-sectionally within derivative users and non-derivative users as in Table 5. Be curious about matching status of the least constrained insurers, Appendix Table C.6 includes the dummy

Table 5: Active duration adjustment: Derivative users and non-derivative users

This table reports regression analysis of the reaction of the overall asset duration to interest rate movements. The full sample includes observations from 2004 to 2018. For the time period from 2004 to 2009 where only non-derivative users are included because the detailed derivative data is not available. Non-derivative users from 2004 to 2009 are identified as those who are below the top 5% percentile in terms of the absolute book value of derivatives. Derivative users in the time period from 2010 and 2018 are are life insurers whose $DV01$ of interest rate derivatives is greater than 5% of $DV01$ of bond portfolios. The dependent variable is the active duration adjustment measured by active duration (defined in Equation 2) divided by total assets. Long-term liability proportion is the value percentage of long-term reserves in total liabilities. The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

	Dependent variable: Active duration adjustment					
	All life insurers		Non-derivative users		Derivative users	
	(1)	(2)	(3)	(4)	(5)	(6)
ΔLevel	−0.131***	−0.127***	−0.129***	−0.121***	0.072	0.166
	(0.037)	(0.031)	(0.038)	(0.032)	(0.188)	(0.233)
ΔTerm spread (10Y-3M)	−0.070***	−0.073***	−0.062**	−0.061***	−0.369***	−0.413***
	(0.024)	(0.021)	(0.025)	(0.022)	(0.127)	(0.135)
ΔTerm spread (30Y-10Y)	−0.486***	−0.464***	−0.514***	−0.487***	0.021	0.188
	(0.115)	(0.090)	(0.118)	(0.093)	(0.444)	(0.472)
ΔLong-term liability proportion	0.773***	0.762***	0.812***	0.815***	−1.600	−1.701*
	(0.164)	(0.294)	(0.167)	(0.294)	(1.017)	(0.984)
ΔLog[total assets] (in thousand)	1.932***	1.618***	1.924***	1.610***	2.122***	2.360***
	(0.058)	(0.134)	(0.059)	(0.135)	(0.494)	(0.806)
Dummy: RBC ratio < 10%	−0.087**	0.007	−0.091**	0.012	−0.208	−0.454**
	(0.043)	(0.070)	(0.044)	(0.071)	(0.292)	(0.176)
Constant	0.553***		0.561***		0.302***	
	(0.015)		(0.016)		(0.072)	
Fixed effects	–	*Firm*	–	*Firm*	–	*Firm*
Observations	8,194	8,194	7,908	7,908	286	286
R^2	0.124	0.264	0.125	0.266	0.122	0.308
Adjusted R^2	0.124	0.183	0.125	0.183	0.103	0.119
Residual Std. Error	1.182	1.141	1.190	1.150	0.896	0.888

Note: *p<0.1; **p<0.05; ***p<0.01

indicating insurers with highest RBC ratios, although no systematical pattern is found there.

6.3 Robustness to other interest rates and insurer groups

Different benchmark interest rates: Corporate bond yields The bond portfolios of life insurers consist of not only industrial bonds but also treasury bonds. The ratio of the two types of bonds being around 3 : 1[16]. It is reasonable to examine the association of duration matching behavior with both treasury yields and corporate bond yields.

[16]The industrial and miscellaneous accounts for 75.7% and government and revenue bonds accounts for 23.2% of total investment. (From Insurance fact book 2019)

The corporate bond yields used in the test are in reference to high quality market (HQM) corporate bonds yields. The HQM yield curve pertains to the high quality corporate bond market, i.e., corporate bonds rated AAA, AA, or A in S&P's ratings. The regression methodology of the HQM curve blends AAA, AA, and A bonds into a single yield curve that represents the market-weighted average quality of high quality bonds. The HQM methodology also projects yields beyond 30 years maturity out through 100 years maturity.

Interest rates tested in Column (1) and (2) are treasury yields where column (1) is from the original specification from Appendix Table **??**. The term spread used in Column (2) is the difference between the 10-year and the 2-year treasury yield, which is another commonly used term spread. In column (3) and (4), HQM corporate bonds yields are tested. The mixed yields in column (5) is the weighted average of treasury yields and HQM corporate bond yields with the ratio of two types of yields being 3 to 1. The ratio is approximately equal to the ratio of government bonds and corporate bonds in the asset portfolio of life insurers.

As shown in column (2), the term spread between the ten-year and the two-year treasury bonds exhibits the same significance as ten-year and three-month spreads, but the magnititute of it is less pronounced than the latter. It might imply that ten-year and the three-month spread is more reliable indicator for life insurers in terms of forecasting the future interest rate change. Using HQM corporate bond yields in column (3) and (4) generates the same association between duration matching behavior and interest rate movements as treasury bond yields. Both the level and the term spread of corporate bond yields are negatively correlated with the asset duration. The weighted average yields of treasury bonds and corporate bonds tested in column (5) remains robust. It provides a more convince evidence than only using treasury yields for the matching pattern of duration with interest rate movements. Because corporate bonds also constitute around 30% of total assets of life insurance companies.

Insurance company groups To test the robustness of the impact of interest rate movement on duration matching, it studies the size-effect of life insurers at the group level. Two types of group-level samples, SNL group and NAIC group, are employed as shown in Table C.8. As in column (3) and (4), the coefficients of the interest level and the slope is consistent with those in column (1) and (2). In the group-level analysis, the sign and the significance of liability risk exposure are consistent with the result using individual company data. Additionally, in column (1) the size-effect of companies measured by the value of total asset is not significant using individual company data. After replace the continuous size measure with a dummy variable of large insurers, the dummy variable is positively significant, which means large insurers hedge more against the interest rate risk. In both group standards as in column (3) and (4), the size-effect is not significant in the SNL company group and the NAIC company group.

Moreover, the robustness of the impact of interest rate factors on the duration matching remains when using the natural logarithm of combined $DV01$ and other covariants. As shown in Table **??**, the sign and the significance of interest rate factors are consistent with previous results.

7 Identification

The section devotes to further verifying the causal effect of interest rate movements on duration matching behavior by ruling out potential endogeneity issue. It is well-documented that the investment behavior of insurers (and, more generally, institutional investors) significantly affects asset prices[17]. In particular, Domanski and Shin (2017) suggests that the decline of long-term interest rates in Europe in 2014 cause life insurance companies and pension funds hunt for long-term bonds which further downward pressure on interest rates.

7.1 2013 taper tantrum

The accidental interest rate event, 2013 taper tantrum is employed as an exogenous shock on the treasury yield market. On May 22 congressional appearance Bernanke first revealed the Federal Open Market committee's (FOMC) thinking on a taper of its quantitative easing program in answering a lawmaker's question. The market reacted to the news dramatically: bond yields rocketed higher and stock prices dropped; financial conditions over the ensuing months tightened, which surprised the Fed. As shown in Figure 7, the interest rate level rose rapidly shortly after the second quarter and the increasing tendency does not disappear until the end of 2013. Simultaneously, the 10-year and 3-month term spread also kept moving upwards almost for the rest of year, which reflected the increasing future rates of the market. According to the hypotheses, facing both the increase of interest rate level and the term spread, life insurers would have less incentive to lengthen asset duration to match up with liability duration. That is, the effect of interest rate shock on the average duration that results from the consideration of duration matching is presumably negative.

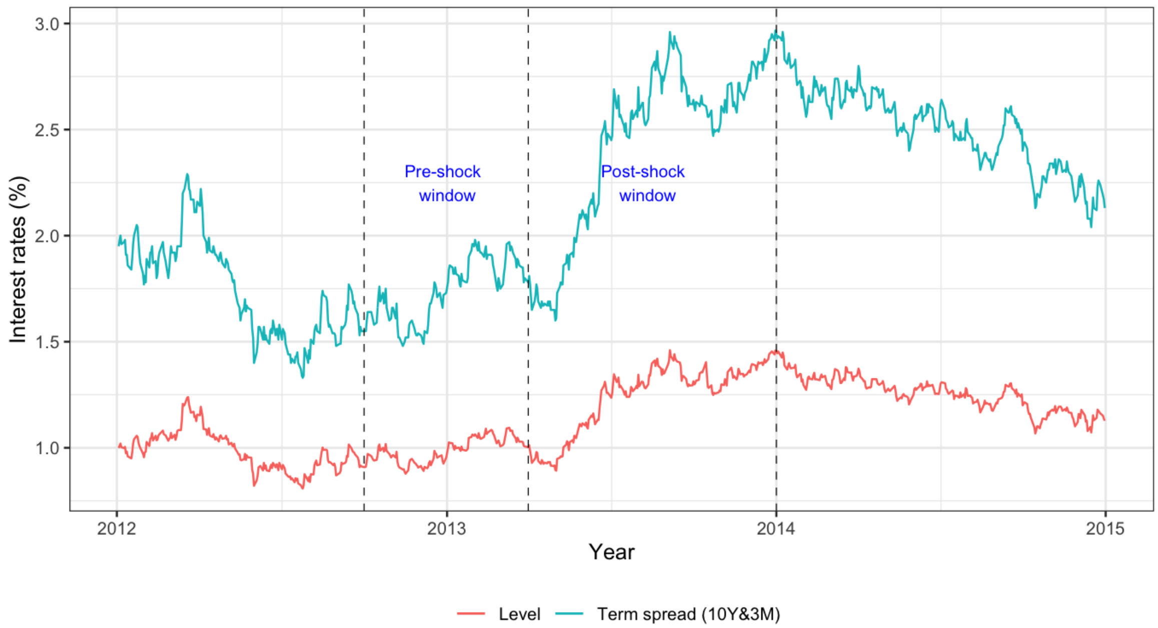
7.2 Difference-in-differences analysis

To isolate the effect of interest rate movements on life insurers from other factors, I employ a DID analysis where two sets of comparison are tested. First, I test how the life insurers who are highly exposed to the interest rate risk differentiate from ones who have relatively low interest rate risk exposure in terms of duration adjustment. Secondly, I consider P&C insurance

[17] See Ellul et al. (2011), Greenwood and Vissing-Jorgensen (2018), Girardi et al. (2018) and Koijen and Yogo (2019)

Figure 7: Interest rate movements around 2013 taper tantrum

The shock of the taper tantrum happened in 2013Q2, which is trigged by Bernanke's speaking in congressional appearance on May 22. The pre-shock window including 2 quarters is from 2012Q4 to 2013Q1. The post-shock windows including three quarters is from 2013Q2 to 2013Q4.



companies as the control group, which are compared with life insurers. Choosing P&C insurers as the control group is valid because they have short-term of liabilities so that do not need to match duration. Traditionally, P&C companies generally have much shorter term of liability than life insurers. They have less exposure to interest rate risk. Duration mismatching is not a consideration in their asset-liability management. In terms of NAIC accounting, the account rule of reserve is not interest-rate-sensitive. The pre-shock period is chosen as the two quarters from 2012Q4 to 2013Q1 because the it is a time period right before the shock where the interest rate movements are relatively stable. The subsequent three months, from 2013Q2 to 2013Q4, are chosen as the post-shock window covers the upwards tendency of both the interest rate level and the term spread. A two month post-shock window until 2013Q3 is also examined for robustness.

To accurately capture adjustment behavior around the taper tantrum, I aggregate the quarterly data from the daily bond transactions which is reported in Part 3, Part 4 and Part 5 of the annual NAIC filling. The observations of the life insurers which have significant derivative holdings are excluded from the sample, because the derivative transaction is not available in the statutory data so that quarterly derivative data cannot be obtained. The data used ranges from Jau 1st 2013 to Dec 31st 2014, two complete years. The quarterly data of asset and long-term liabilities holding is computed from annual records by assuming the even quarterly change within each year.Baseline specification is as Equation 4. The dummy variable "After shock" takes the value for the time t after the shock happened. Life insurer$_i$ is the dummy indicating life insurers. X_{it} denotes other insurer attributes.

$$Ad_{it} = \beta_1 \text{After shock}_t + \beta_2 \text{Life insurer}_i + \gamma \text{After shock}_t \times \text{Life insurer}_i + \Gamma \Delta X_{it} + \epsilon_{it} \ . \tag{4}$$

A continuous DID specification (Acemoglu, et al, 2004) where the continuous measure of interest rate risk exposure replaces the dummy indicator of the treatment group, life insurers. The interest rate risk exposure in the liability portfolio can be measured continuously by the proportion of long-term liabilities. In the following specification, LLP_{it} denoting the long-term liability proportion takes value zero for P&C insurers.

$$Ad_{it} = \beta_1 \text{After shock}_t + \beta_2 \text{LLP}_{it} + \gamma \text{After shock}_t \times \text{LLP}_{it} + \Gamma \Delta X_{it} + \epsilon_{it} \ . \tag{5}$$

Table 6 summarizes the DID estimates comparing life insurers with high exposure of interest rate risk. As shown with the positive sign of the post-shock dummy, life insurers on average increase their asset duration after the revealing of the possible taper. The significant positive sign of interaction term indicates that the treatment group, life insurers with more long-term liabilities increases less average duration relative to ones with low risk exposure. This is consistent with the hypothesized effect of the taper shock on the asset duration: both the increasing of the interest rate level and the term spread reduces the incentive of life insurers to match up the asset duration with liability duration. This implies that the taper tantrum imposes a negative impact on those life insurers who are more exposure to the interest rate risk, which is verified by the negative significant coefficient of the interaction. To measure the treatment rate, the treatment dummy is replaced with the proportion of long-term liabilities, which is to proxize the interest rate risk exposure of liabilities. The coefficients of the new interaction remain negative, which are significant in the post-shock window of three quarters, but the window of two quarters. As a robustness test, Table 7 uses the P&C insurers, which have no demand to match duration, as the control group. The same correlation as in Table 6 is derived. It restates that life insurers add less duration into their bond portfolio relative to P&C insurers after the tape tantrum, which is due to the consideration of duration matching.

Column (1) use two dummy variables to indicate the time period after shock and life insurers. Then, in column (2) and (3) the after-shock-dummy is further replaced with the interest rate factors, the level and the term spread, which are continuous so that can more precisely specify the magnititute of the shock. Furthermore, since the essential difference of life insurers from P&C insurers in terms to duration-matching is resulted from their long-term liability exposure.

Table 6: Difference-in-differences: High interest rate risk exposure v.s. low interest rate risk exposure

This table reports the DID result comparing life insurers with high exposure of interest rate risk. The shock of the taper tantrum happened in 2013Q2. The pre-shock period including 2 quarters is from 2012Q4 to 2013Q1. Two different post-shock windows are tested, which are from 2013Q2 to 2013Q3 (two quarters) and from 2013Q2 to 2013Q4 (two quarters), respectively. The treatment group is those life insurers whose long-term liabilities account for more 50% of total liabilities. The rest of life insurers (long-term liability proportion $< 50\%$) are considered as the control group. All specifications are estimated with the OLS model and tested on quarterly data.

	Dependent variable: Active duration adjustment					
	Post-shock window: Two quarters			Post-shock window: Three quarters		
	(1)	(2)	(3)	(4)	(5)	(6)
Post-shock	0.223***	0.220***	0.199***	0.136***	0.132***	0.109***
	(0.018)	(0.018)	(0.022)	(0.015)	(0.015)	(0.018)
Highly exposed life insurers	0.101***	0.098***		0.103***	0.100***	
	(0.015)	(0.015)		(0.016)	(0.016)	
ΔLong-term liability proportion			0.137***			0.139***
			(0.019)			(0.019)
ΔLog[total assets] (in thousand)		0.195***	0.191***		0.175***	0.174***
		(0.051)	(0.051)		(0.037)	(0.036)
Post-shock × Highly exposed life insurers	−0.067**	−0.063**		−0.076***	−0.072***	
	(0.028)	(0.028)		(0.025)	(0.025)	
Post shock × Long-term liability proportion			−0.060			−0.066*
			(0.040)			(0.035)
Observations	2,164	2,164	2,164	2,704	2,704	2,704
R^2	0.028	0.034	0.042	-0.002	0.006	0.012
Adjusted R^2	0.027	0.033	0.040	-0.004	0.005	0.011
Residual Std. Error	0.383 (df = 2161)	0.382 (df = 2160)	0.380 (df = 2160)	0.393 (df = 2701)	0.391 (df = 2700)	0.390 (df = 2700)

Note: *p<0.1; **p<0.05; ***p<0.01

In Column (5) and (6) it uses the proportion of long-term liability to replace life insurer dummy variable, which is a more precise specification. All intersection terms are negatively significant: after taper tantrum life insurers have relatively lower duration exposure in their assets compared with P&C insurers. Specifically, the high interest rate level or term spread after the taper tantrum causes life insurers to response with a lower the duration exposure relative to P&C insurers.

8 Conclusion

This paper provides an understanding of duration matching behavior by disentangling the two different impact of interest rate movement on life insurers. Life insurers have the incentive to adjust the duration gap based on the current interest rate level because of the convexity difference portfolios causes life insurers to deviate from the optimal level of duration matching with the interest rate fluctuation. So they would like to restore the duration-matching to the optimal level that what they choose to bear. The ex ante adjustment is driven by life insurers'

Table 7: Difference-in-differences: impact of taper tantrum on life insurers

The shock of the taper tantrum happened in 2013Q2. The pre-shock period including 2 quarters is from 2012Q4 to 2013Q1. Two different post-shock windows are tested, which are from 2013Q2 to 2013Q3 (two quarters) and from 2013Q2 to 2013Q4 (three quarters), respectively. The treatment group is life insurers and the control is P&C insurers. All specifications are the OLS model and tested on quarterly data.

	Dependent variable: Active duration adjustment					
	Post-shock window: Two quarters			Post-shock window: Three quarters		
	(1)	(2)	(3)	(4)	(5)	(6)
Dummy: Post-shock	0.171***	0.168***	0.170***	0.098***	0.096***	0.097***
	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Dummy: Life insurer	0.085***	0.082***		0.086***	0.083***	
	(0.010)	(0.010)		(0.011)	(0.010)	
ΔLong-term liability proportion			0.134***			0.136***
			(0.018)			(0.019)
ΔLog[total assets] (in thousand)		0.341***	0.341***		0.317***	0.316***
		(0.020)	(0.020)		(0.017)	(0.018)
Post-shock × Life insurer	−0.029*	−0.027*		−0.036**	−0.036***	
	(0.015)	(0.015)		(0.014)	(0.014)	
Post-shock × Long-term liability proportion			−0.019			−0.048*
			(0.027)			(0.025)
Observations	12,824	12,818	12,263	15,930	15,924	15,254
R^2	0.019	0.041	0.041	-0.001	0.019	0.019
Adjusted R^2	0.019	0.040	0.041	-0.001	0.019	0.018
Residual Std. Error	0.377 (df = 12821)	0.373 (df = 12814)	0.373 (df = 12259)	0.386 (df = 15927)	0.382 (df = 15920)	0.383 (df = 15250)
Note:						*p<0.1; **p<0.05; ***p<0.01

anticipation of the future interest rate. If life insurers can foresee the change in the future interest rates, by adjusting the duration gap ex ante they have the opportunity to mitigate the surplus loss during the adverse interest rate fluctuation (or enhance surplus value during the favorable interest rate fluctuation).

The empirical investigation on the U.S. life insurance industry for the time period from 2010 to 2018 confirms the negative association of the interest rate level and slope with combined asset duration. It further shows that the combined dollar duration in the asset and derivative portfolios is negatively associated with the level and slope of the term structure. Exploiting 2013 taper tantrum as the identification strategy, the DID analysis using P&C insurers as the control group shows that life insurers increase less duration exposure through bond trading after shock relative to P&C insurers. The reduction of increasing duration exposure persists for three quarters, which is positively correlated with the proportion of long-term liabilities and also with the term spread.

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A Data

Treasure rates We use ten years' treasury rate as a presentative rate that life insurers refer to when they make investment decision. The monthly data of 10 year's treasury rate is widely available. The time period from January 2003 to November 2018 is chosen as the window of observation. In particular, the monthly rate is usually the treasury rate calculated on the rest day of each month.

Derivative data The derivative information is obtained from Schedule DB of the NAIC regulatory report where it includes transactions and holding data of each derivatives. During the sample period from 2010 to 2018, the holding information of derivatives is reported in Part A Section 1. It records all options, caps, floors, collars, swaps and forwards holding information as of the report date (December 31) of the year. S&P Global market intelligence (previous SNL financial) aggregates the information of Schedule DB for all each life insurer year by year. This paper export the aggregated data from this data platform.

To server the purpose of this paper, it needs to identify derivatives that are used to hedge the interest rate risk. First, the derivatives of interest are those used to hedge the interest rate risk, not other types of risk. Then, the recognition[18] of derivatives should be hedging. Finally, because it is not able to compute the duration for forward derivatives using information available in Schedule DB and also the risk exposure of forward contracts are very limited, this paper does not include the forward holding in the sample.

Since 2010 insurers has been required to specify the type of risk that each derivative position hedges against, such as interest rate risk, default credit default risk and foreign exchange risk. This paper focus on derivatives to hedge against the interest rate risk[19]. The formate of risk specification is not completely uniform. In particular, some insurers use single letter or numbers instead of complete words to indicate different types of risks. For these insures, it needs to dig into the Schedule BD of their annual statutory report to check the definition of these notations.

Financial constraints Two types of data are used to measure the extent of being financial constrained. One is the RBC ratio, which is used by Ellul etc. (2011). In this paper, life insurers are categorized into three groups according to their company action level RBC ratios. The least and the more constrained constrained group are those whose RBC ratios falls into the top and the bottom 25 percentile; the rest of insurers are the middle group.

[18] Other categories of derivative recognition are replication, income generation and "other" category.

[19] The risk hedged by each derivative position is not available in Schedule DB before year 2010, which is also the reason the sample period of this paper starts from year 2010.

Financial strength ratings evaluated by A.M. Best[20] is another measure of financial strength used in the paper. In general, AM Best assigns one financial strength rating to each company identified by one unique NAIC number. However, it exists the case where life insurance entity identified by one NAIC number but owning multiple subsidiaries are evaluated with respect to each subsidiary so that they could be assigned to different ratings for different subsidiaries. In this case, an average ratings of all subsidiaries is computed to be associated with the life insurance company who are assigned different ratings for its subsidiaries.

Bond transaction Data: The insurance statutory data in Part 3, Part 4 and Part 5 of Schedule D fills transaction records of long-term bonds and stock. Part 3 reports all bond holdings acquired but not disposed yet in the current filling year and Part 4 reports all bond holdings disposed but not acquired in the current filling year. All bond holdings that are both acquired and disposed in the current filling year are report in Part 5.

The type of transactions in terms of security types can be identified by the line numbers, which is specified by SNL team. If exporting data from Screener, bond transactions and stock transactions are already separated.

The bond issue information in Part 3, Part 4 and Part 5 of Schedule D is not as complete as that in Part 1, long-term bond holding records (only Part 4 reports the maturity of each bond transacted). But the full CUSIP is reported, which can be used to look up the maturity, coupon rates, and coupon payment frequency. For instance, using CUSIP one can link transaction data with bond issue information in Fixed Income Securities Database (FISD). Alternatively, I linked the bond issue information exploiting the Screener function of S&P Global market intelligence where bond transactions and stock transactions are separated and bond issue information can be directly added through field selector. There are two drawback of this approach. First, it is that the coupon frequency is not available in this way; a simplified assumption of the frequency is needed (assume semi-annually paid). Second, there is date exporting limit so that it needs export data manually for multiple times.

B Measure construction

B.1 Asset duration

To calculate asset duration, the information of each insurer' investment portfolio is required. Insurance investment holding data in S&P Global Market Intelligence (SNL) provides the annually bonds holding information. It includes the holding data of all U.S. life insurers and the

[20] Here to acknowledge that A.M. Best generally shares financial strength ratings of U.S. life insurance company from 2010 to 2019.

time range is from 2004 to 2018.

The idea of a relatively simply measure of the asset duration is combining the carrying value and the time to maturity to form an approximate of duration. The duration of an insurer in a year is the average year to maturity weighted by carrying value of the bond portfolio. The annual carrying value of holding bonds and the maturity of them are exported from the section of the insurance investment.

Construct the duration measure of the bond portfolio For a bond with coupon payment and the principal being C and F. Its annual effective interest rate is i and the nominal interest rate in one coupon payment period is y, so it has $(1+y)^m = 1+i$, where m is the coupon frequency per year. N is the total number of payment periods of coupon in the rest life of the bond. The duration following directly from the definition is the first order derivative of price with respect to yield divided by price. The price and the duration of the bond are calculated as:

$$P = \frac{C}{1+y} + \frac{C}{(1+y)^2} + \cdots + \frac{C+F}{(1+y)^N} = \frac{C[1-(1+y)^{-N}]}{y} + \frac{F}{(1+y)^N};$$

$$\frac{dP}{di} = \frac{dP}{dy}\frac{dy}{di} = \{-\frac{C[1-(1+y)^{-N}]}{y^2} + \frac{NC}{y(1+y)^{N+1}} - \frac{NF}{(1+y)^{N+1}}\} \times \frac{1}{m}(1+i)^{1/m-1};$$

$$\text{duration} = -\frac{dP}{di} \times \frac{1}{P}.$$

The special case is the bonds without coupons or whose coupon is only paid at maturity, the duration is reduced as the time to maturity in years. The portfolio duration is the average duration of bonds in the portfolio weighted by their fair value.

B.2 Derivative duration

The blow list the assumptions that simplifying the calculation of $DV01$ of interest rate derivatives:

Swaps

- The payment frequency of the fixed leg is assumed to be semi-annual. The fixed rate is in reference to the swap yield curve at statutory report dates.
- The float rate is in reference to the 3 month LIBOR as it is most common floating index in the derivative holding information reported to NAIC. The payment frequency of the float leg is, therefore, assumed to be quarterly.

- The discount rates is in reference to the U.S. treasury yield curve in order to keep consistent with the discount rate used to compute bond duration.

- The time to maturity from the reporting date to the expiration date is taken as the maturity of the swap.

Caps and floors:

- The information of payment frequency is incomplete in the NAIC report. Here it assumes that the payments are twice per year since the interest rate derivatives are typically paid semi-annually.

- The float rate of cap is in reference to the 3 month LIBOR as it is most common floating index in the derivative holding information reported to NAIC. The payment frequency of the float leg is assumed to be quarterly.

- The discount rates is in reference to the U.S. treasury yield curve in order to keep consistent with the discount rate used to compute bond duration.

- The time to maturity from the reporting date to the expiration date is taken as the maturity of the swap.

- The $DV01$ of caps is exported from Bloomberg Terminal. Then, the $DV01$ of interest rate floors can be obtained from the put-call parity.

Relation of $DV01$ and $\frac{\partial P}{\partial r}$: the $DV01$ measures the change in present value caused by one basis point of the interest rate, namely, $DV01 = P(r + 0.01\%) - P(r)$. Applying the Taylor expansion to the expression, it gives

$$DV01 = \frac{\partial P(r)}{\partial r} \times 0.01\% + \frac{\partial^2 P(r)}{\partial r^2} \times (0.01\%)^2 + \cdots .$$

Thus, $DV01$ can be proximately equal to $\frac{\partial P(r)}{\partial r} \times 0.01\%$.

B.3 Measure of interest rate movement

The holding information of bonds is from Schedule D Part 1A Section 1 of the annual statutory report. As showed in the table below held bonds are divided into 5 maturity ranges. First, for each maturity range, use the average of corresponding spot rates of treasury bonds within the range as the average rate of this range. Then, calculate the weighted average of these rates for these maturity ranges, which is the measure of the weighted interest rate level. The weights of each maturity ranges is determined by the value proportion of bonds falling into that maturity range. The value used is the aggregate carrying value of the life insurance industry in the entire sample period. Figure C.1 shows that the value proportion of bonds in each maturity range does not have substantial change during the sample period.

Maturity ranges	Spot rates averaged for each range
1 year or less	Average rate of 1-month, 3-month, 6-month, 1-year
over 1 year through 5 years	Average rates of 1-year, 2-year, 3-year, 5-year
over 5 years through 10 years	Average rates of 5-year, 7-year, 10-year
over 10 years through 20 years	Average rates of 10-year, 20-year
over 20 years	Average rates of 20-year, 30-year

C Figures and tables

Figure C.1: Maturity distribution of the bond holding of the life insurance industry
The figure illustrate the proportion of the held bonds by the life insurance industry that fall into each maturity bucket. The proportion is calculated based on the carrying value of bonds at the statutory reporting date, December 31th of each year. The data is from Schedule D Part 1A Section 1 of the annual statutory report.

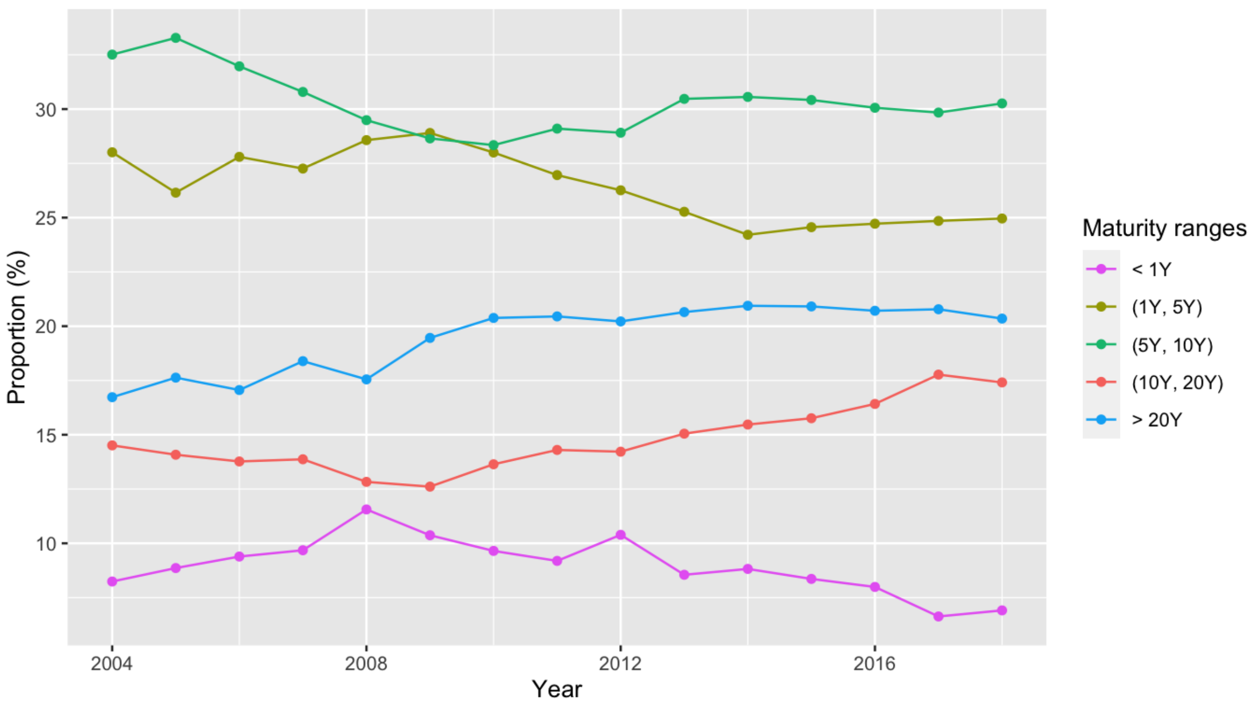

Figure C.2: Interpolate yield curves

In this figure it interpolates the complete treasury yield curves at three dates. The complete yield curves are interpolated by assuming the implied forward rates between two known spots rates with closest terms to be equal. The red and green curves are examples of upward yield curve and the blue one is more of flat yield curve.

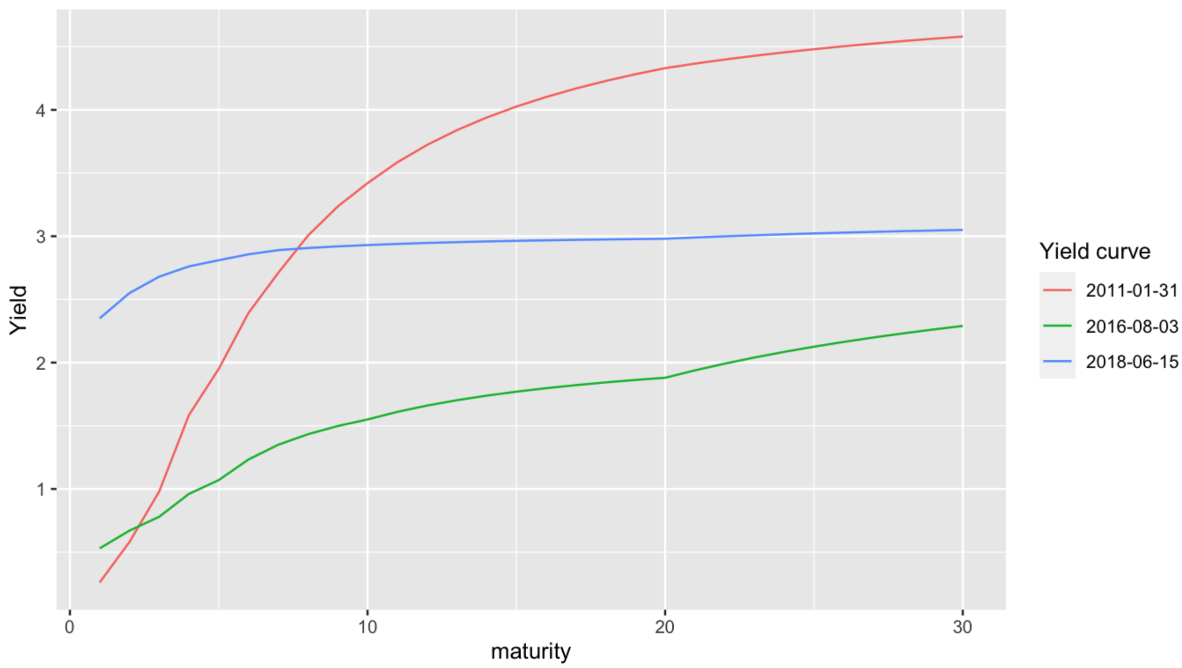

Table C.1: Insurance exposure by policyholders' ages

This table summarize the exposure of insurance and annuity products by type. In addition, the age cohort of each exposure data is also specified. The exposure of each type products in each of age cohorts is measured by two variables. One is the percentage of polices by their number within the same type of polices. The other exposure variable is the average face value / premium of a certain type of police in each age cohort.

	term life insurance								whole life		universal life		variable annuity	
Age cohort	exposure of policies (YRT)	average exposure in face value (YRT)	exposure of policies (10-Year LPT)	average exposure in face value (10-Year LPT)	exposure of policies (20-Year LPT)	average exposure in face value (20-Year LPT)	exposure of policies (30-Year LPT)	average exposure in face value (30-Year LPT)	exposure of policies	average exposure in face value	exposure of policies	average exposure in face value	exposure of policies	average premium
0-4	4%	$34,000	1%	$142,000	0	$172,000	0	$206,000.00	7%	$80,000	7%	$49,000	24%	$132,026
5-9														
10-14														
15-19														
20-24	24%	$233,000	9%	$419,000	10%	$404,000	16%	$421,000.00	6%	$81,000	9%	$64,000		
25-29														
30-34	50%	$349,000	25%	$591,000	43%	$599,000	58%	$616,000.00	9%	$116,000	10%	$132,000		
35-39														
40-44	18%	$389,000	32%	$684,000	34%	$600,000	24%	$575,000.00	13%	$120,000	16%	$170,000		
45-49														
50-54	4%	$408,000	25%	$662,000	12%	$484,000	2%	$545,000.00	19%	$90,000	24%	$156,000		
55-59														
60-64		$430,000	8%	$675,000	1%	$473,000	0%	$0.00	19%	$60,000	20%	$138,000	22%	$151,014
65-69													24%	$149,345
70-74									27%	$30,000	14%	$196,000	16%	$144,806
75-79													9%	$143,654
80-84													6%	$150,283
85-89														
90-94														
95-99														

Table C.2: Exposure proportion by types of life insurance industry products

The table reports the exposure proportion of insurance and annuity products by types.

Life insurance	29.69%		
	Whole life	6.30%	
	Universal life	7.20%	
	Term life	16.19%	
		Yearly renew term	1.55%
		10-year level premium term	3.26%
		15-year level premium term	1.38%
		20-year level premium term	8.79%
		30-year level premium term	1.22%
Annunity	70.31%		
	Fixed annutiy	19.18%	
	Variable annuity	51.13%	

Table C.3: Industrial holding in the general account and separate account (As of 2014)

This table reports the aggregate holding of the life insurance industry in terms of bond portfolios and insurance and annuity reserve. The unit of the amount in the table is thousand dollar.

	Bonds	Life insurance reserve	Annuity reserve
General account	5370201984	2031864712	2731094781
Separate account	326039764	279522598	1855471244

Table C.4: Correlation matrix of interest rate factors

The table shows the correlation matrix of interest rate factors. The sample period to calculate Pearson coefficients is from 2004 to 2018. Variable "Level" is the simple average of a sequence of spot rates on the treasury yields, including those of 1-month, 3-month, 6-month, 1-year, 2-year, 5-year, 10-year, 20-year and 30-year treasury bonds. Variable "Level (weighted)" is the average of the same spot rates weighted by the holding information of bonds with the corresponding maturity.

	Level (simple average)	Level (weighted average)	Term spread (10Y&3M)	Term spread (10Y&2Y)	Term spread (30Y&10Y)
Level (simple average)	1	0.975	-0.639	-0.665	-0.789
Level (weighted average)	0.975	1	-0.460	-0.514	-0.719
Term spread (10Y&3M)	-0.639	-0.460	1	0.954	0.715
Term spread (10Y&2Y)	-0.665	-0.514	0.954	1	0.817
Term spread (30Y&10Y)	-0.789	-0.719	0.715	0.817	1

Table C.5: Overall duration adjustment: derivative users and non-derivative users

The table compares duration adjustment across interest rate derivative users and non-derivative users. The sample period is from 2010 to 2018. For the time period from 2004 to 2009, as lack of derivative data to compute its duration exposure, only non-derivative users are included in the sample. Non-derivative users are determined as those who are below the top 5% percentile in terms of the absolute book value of derivatives. The dependent variable "average duration" is defined as the combined asset dollar duration divided by total assets. "Level (spot rates)" is the average of a sequence of spot rates on the treasury yield curve. "Level (forward rates)" is the average of the forward rates of the yield curve.Long-term liability proportion is the value percentage of long-term reserves in total liabilities. The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

	Dependent variable: Average duration						
	All life insurers			Non-derivative users		Derivative users	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Level	-0.186***	-0.334***	-0.373***	-0.323***	-0.407***	-0.341**	-0.845**
	(0.025)	(0.041)	(0.037)	(0.041)	(0.037)	(0.150)	(0.349)
Term spread (10y&3m)		-0.270***	-0.329***	-0.258***	-0.344***	-0.384**	-0.761***
		(0.039)	(0.052)	(0.040)	(0.053)	(0.157)	(0.262)
Long-term liability proportion	1.875***	1.968***	3.377***	2.150***	3.201***	-4.367	7.249***
	(0.433)	(0.436)	(0.111)	(0.434)	(0.112)	(3.879)	(0.811)
Log[total assets] (in thousand)	0.605***	0.504***	0.186***	0.495***	0.236***	-0.182	-0.136
	(0.134)	(0.136)	(0.014)	(0.138)	(0.015)	(0.663)	(0.118)
Dummy: RBC ratio < 10%	-0.137	-0.131	0.187	-0.128	0.123	-0.495	3.160***
	(0.136)	(0.137)	(0.122)	(0.138)	(0.123)	(0.544)	(0.853)
Constant			4.059***		3.694***		8.062***
			(0.273)		(0.276)		(2.333)
Fixed effects	Firm	Firm	-	Firm	-	Firm	-
Observations	9,107	9,107	9,107	8,802	8,802	305	305
R^2	0.806	0.808	0.116	0.809	0.122	0.893	0.300
Adjusted R^2	0.786	0.789	0.116	0.789	0.121	0.866	0.289
Residual Std. Error	1.717	1.707	3.492	1.711	3.488	1.186	2.736
Note:					*p<0.1; **p<0.05; ***p<0.01		

Table C.6: Active duration adjustment: RBC ratios

This table reports regression analysis of the reaction of the overall asset duration to interest rate movements. The full sample includes observations from 2004 to 2018. For the time period from 2004 to 2009 where only non-derivative users are included because the detailed derivative data is not available. Non-derivative users from 2004 to 2009 are identified as those who are below the top 5% percentile in terms of the absolute book value of derivatives. Derivative users in the time period from 2010 and 2018 are are life insurers whose $DV01$ of interest rate derivatives is greater than 5% of $DV01$ of bond portfolios. The dependent variable is the active duration adjustment measured by active duration (defined in Equation 2) divided by total assets. Long-term liability proportion is the value percentage of long-term reserves in total liabilities. The dummy variables of RBC ratios indicates the insures whose RBC ratios are below 10% percentile and above 90% percentile, respectively.

	Dependent variable: Active duration adjustment					
	(1)	(2)	(3)	(4)	(5)	(6)
*Delta*Level	−0.131***	−0.131***	−0.131***	−0.127***	−0.127***	−0.127***
	(0.037)	(0.037)	(0.037)	(0.031)	(0.031)	(0.031)
*Delta*Term spread (10Y-3M)	−0.070***	−0.070***	−0.070***	−0.073***	−0.073***	−0.073***
	(0.024)	(0.024)	(0.024)	(0.021)	(0.021)	(0.021)
*Delta*Term spread (30Y-10Y)	−0.486***	−0.487***	−0.486***	−0.464***	−0.464***	−0.464***
	(0.115)	(0.115)	(0.115)	(0.090)	(0.091)	(0.091)
Delta Long-term liability proportion	0.773***	0.769***	0.774***	0.762***	0.763***	0.763***
	(0.164)	(0.164)	(0.164)	(0.294)	(0.294)	(0.294)
*Delta*Log[total assets] (in thousand)	1.932***	1.930***	1.930***	1.618***	1.619***	1.619***
	(0.058)	(0.058)	(0.058)	(0.134)	(0.133)	(0.134)
Dummy: RBC ratio < 10%	−0.087**		−0.090**	0.007		0.007
	(0.043)		(0.043)	(0.070)		(0.070)
Dummy: RBC ratio > 90%		−0.047	−0.056		0.034	0.034
		(0.061)	(0.062)		(0.117)	(0.117)
Constant	0.553***	0.547***	0.556***			
	(0.015)	(0.015)	(0.016)			
Fixed effects	–	–	–	*Firm*	*Firm*	*Firm*
Observations	8,194	8,194	8,194	8,194	8,194	8,194
R^2	0.124	0.124	0.124	0.264	0.264	0.264
Adjusted R^2	0.124	0.123	0.124	0.183	0.183	0.183
Residual Std. Error	1.182	1.182	1.182	1.141	1.141	1.141

Note: *p<0.1; **p<0.05; ***p<0.01

Table C.7: Duration matching and corporate bond yields

This table tests the association between corporate bond yields and duration adjustment. The corporate bond yields are in reference to high quality market (HQM) corporate bonds yields. The mixed yields in column (5) is the weighted average of treasury yields and HQM corporate bond yields with the ratio of two types of yields being 3 to 1. The ratio is approximately equal to the ratio of government bonds and corporate bonds in the asset portfolio of life insurers. Long-term liability proportion is the value percentage of long-term reserves in total liabilities.

	Dependent variable: Combined DV01 / total assets (%)				
	Treasury yields		HQM corporate yields		Mixed yields
	(1)	(2)	(3)	(4)	(5)
Level: treasury bonds	-0.269***	-0.267***			
	(0.037)	(0.038)			
Term spread (10y&3m): treasury bonds	-0.114***				
	(0.025)				
Term spread (10y&2y): treasury bonds		-0.086***			
		(0.026)			
Level: corporate bonds			-0.292***	-0.288***	
			(0.037)	(0.037)	
Term spread (10y&6m): corporate bonds			-0.056***		
			(0.020)		
Term spread (10y&2y): corporate bonds				-0.058***	
				(0.022)	
Level: mixed yields					-0.281***
					(0.039)
Term spread (10y&2y): mixed yields					-0.082***
					(0.025)
Long-term liabilities proportion	0.015***	0.015***	0.015***	0.015***	0.015***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Log[total assets] (in billion)	0.004***	0.004***	0.004***	0.004***	0.004***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Dummy: RBC ratio < 10%	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Fixed effects	Firm	Firm	Firm	Firm	Firm
Observations	5,318	5,318	5,318	5,318	5,318
R^2	0.050	0.048	0.050	0.050	0.049
Adjusted R^2	-0.088	-0.090	-0.087	-0.088	-0.089
F Statistic (df = 5; 4643)	48.519***	46.595***	49.321***	49.070***	47.529***
Note:			*p<0.1; **p<0.05; ***p<0.01		

Table C.8: Duration adjustment and interest rates (Robustness test: company group level)

This table focus on the size-effect testing on the individual-level and the group-level data. Observations in column (1) and (2) are individual life insurance companies. Observations in column (3) and (4) are SNL groups and NAIC groups, respectively.

	Dependent variable: Combined DV01 / total asset			
	Individual insurers	Individual insurers	SNL insurer groups	NAIC insurer groups
	(1)	(2)	(3)	(4)
Level	-0.026***	-0.026***	-0.026***	-0.032***
	(0.004)	(0.004)	(0.005)	(0.005)
Slope (10y&3m)	-0.017***	-0.016***	-0.013***	-0.010***
	(0.003)	(0.002)	(0.004)	(0.004)
Total assets (in billion)	0.00000		0.0002	0.0002
	(0.0003)		(0.0003)	(0.0003)
Dummy: large insurer		0.046***		
		(0.015)		
Saled long-term liabilities	0.260***	0.260***	0.156***	0.188***
	(0.021)	(0.021)	(0.033)	(0.036)
Dummy: RBC ratio < 10%	-0.008	-0.008	-0.004	-0.005
	(0.008)	(0.008)	(0.011)	(0.010)
Fixed effects	Individual	Individual	Individual	Individual
Observations	5,318	5,318	2,678	2,625
R^2	0.045	0.047	0.021	0.028
Adjusted R^2	-0.094	-0.092	-0.116	-0.107
F Statistic	43.741*** (df = 5; 4643)	45.614*** (df = 5; 4643)	10.166*** (df = 5; 2347)	13.286*** (df = 5; 2303)

Table C.9: Duration adjustment and interest rate movements (alternative measures)

The sample period is from 2010 to 2018. For the time period from 2004 to 2009, as lack of derivative data to compute its duration exposure, only non-derivative users are included in the sample. Non-derivative users are determined as those who are below the top 5% percentile in terms of the absolute book value of derivatives. Covariant "Level (simple average)" is the simple average of a sequence of spot rates on the treasury yield curve. Covariant "Level (weighted average)" is the average of the same spot rates weighted by the holding information of bonds with the corresponding maturity. The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

	Dependent variable: Average duration (asset dollar duration / total assets)					
	Level (simple average)			Level (weighted average)		
	(1)	(2)	(3)	(4)	(5)	(6)
Level (simple average)	-0.225***	-0.383***	-0.330***			
	(0.029)	(0.047)	(0.052)			
Term spread (10y&3m)		-0.290***			-0.173***	
		(0.042)			(0.030)	
Term spread (30y&10y)			-0.497***			-0.465***
			(0.174)			(0.143)
Level (weighted average)				-0.334***	-0.430***	-0.451***
				(0.041)	(0.050)	(0.061)
Long-term liability proportion	1.864***	1.963***	1.899***	1.903***	1.965***	1.944***
	(0.470)	(0.474)	(0.471)	(0.473)	(0.475)	(0.475)
Log[total assets] (in thousand)	0.585***	0.477***	0.534***	0.529***	0.468***	0.475***
	(0.148)	(0.149)	(0.151)	(0.148)	(0.149)	(0.152)
Dummy: RBC ratio < 10%	-0.178	-0.171	-0.177	-0.176	-0.172	-0.175
	(0.153)	(0.156)	(0.154)	(0.154)	(0.156)	(0.155)
Fixed effects	Firm	Firm	Firm	Firm	Firm	Firm
Observations	9,107	9,107	9,107	9,107	9,107	9,107
R^2	0.781	0.783	0.782	0.783	0.784	0.783
Adjusted R^2	0.759	0.761	0.759	0.761	0.762	0.761
Residual Std. Error	2.002	1.992	2.000	1.994	1.989	1.992

Note: *p<0.1; **p<0.05; ***p<0.01

Table C.10: Active duration adjustment and interest rate movements (alternative measures)

The sample period is from 2010 to 2018. For the time period from 2004 to 2009, as lack of derivative data to compute its duration exposure, only non-derivative users are included in the sample. Non-derivative users are determined as those who are below the top 5% percentile in terms of the absolute book value of derivatives. Covariant "Level (simple average)" is the simple average of a sequence of spot rates on the treasury yield curve. Covariant "Level (weighted average)" is the average of the same spot rates weighted by the holding information of bonds with the corresponding maturity.The dummy variable of RBC ratios indicates the insures whose RBC ratios are below 10% percentile.

	Dependent variable: Active duration adjustment								
	Level (simple average)				Level (weighted average)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ΔLevel (simple average)	-0.019	-0.074**	-0.131***	-0.127***					
	(0.025)	(0.031)	(0.037)	(0.031)					
ΔTerm spread (10y&3m)	-0.073***		-0.070***	-0.073***		-0.063***		-0.026	-0.030*
	(0.024)		(0.024)	(0.021)		(0.018)		(0.020)	(0.018)
ΔTerm spread (30y&10y)		-0.496***	-0.486***	-0.464***			-0.520***	-0.450***	-0.440***
		(0.115)	(0.115)	(0.090)			(0.102)	(0.116)	(0.091)
ΔLevel (weighted average)					0.049**	-0.012	-0.127***	-0.128***	-0.129***
					(0.022)	(0.028)	(0.041)	(0.041)	(0.035)
ΔLong-term liability proportion	0.798***	0.773***	0.773***	0.762***	0.794***	0.799***	0.769***	0.774***	0.763***
	(0.164)	(0.164)	(0.164)	(0.294)	(0.164)	(0.164)	(0.164)	(0.164)	(0.294)
ΔLog[total assets] (in thousand)	1.925***	1.931***	1.932***	1.618***	1.924***	1.924***	1.932***	1.931***	1.617***
	(0.058)	(0.058)	(0.058)	(0.134)	(0.058)	(0.058)	(0.058)	(0.058)	(0.134)
Dummy: RBC ratio < 10%	-0.087**	-0.087**	-0.087**	0.007	-0.088**	-0.087**	-0.087**	-0.087**	0.008
	(0.043)	(0.043)	(0.043)	(0.070)	(0.043)	(0.043)	(0.043)	(0.043)	(0.070)
Constant	0.575***	0.564***	0.553***		0.590***	0.576***	0.555***	0.555***	
	(0.014)	(0.015)	(0.015)		(0.014)	(0.015)	(0.016)	(0.016)	
Fixed effects	-	-	-	Firm	-	-	-	-	Firm
Observations	8,194	8,194	8,194	8,194	8,194	8,194	8,194	8,194	8,194
R^2	0.122	0.123	0.124	0.264	0.121	0.122	0.124	0.124	0.263
Adjusted R^2	0.122	0.123	0.124	0.183	0.121	0.122	0.123	0.123	0.183
Residual Std. Error	1.183	1.182	1.182	1.141	1.184	1.183	1.182	1.182	1.141
Note:							*p<0.1; **p<0.05; ***p<0.01		