The Long-term Interest Rate and Corporate Bond Credit Spreads*

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– Preliminary Draft –

Abstract
I document a major shift in the comovement between the long-term interest rate and corporate bond credit spreads. Before the Great Financial Crisis, there was no apparent correlation between the 10-year Treasury yield and bond credit spreads. However, after the Financial Crisis, corporate bond credit spreads counterintuitively rose when the 10-year Treasury yield was low, particularly for lower credit ratings. Next, I demonstrate that this new comovement is closely linked to life insurers’ duration mismatch and bond holdings. After increases in the 10-year Treasury yield, the credit spreads on bonds with greater life insurance ownership decrease by more. This relationship was absent before the Financial Crisis when life insurers were hedged against interest rate risk but became pronounced afterward when life insurers faced severe duration mismatch. I then propose an intermediary asset pricing model to explain these findings. In this model, life insurers’ liabilities have a longer duration than their assets. As the long-term interest rate declines, insurers incur equity losses. Consequently, their effective risk aversion rises, leading to higher equilibrium credit spreads.

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1 Introduction

The US corporate bond market has expanded dramatically in recent years and has surpassed the bank loan market to become the main funding source for US corporations. In 2022, the total outstanding US corporate bonds amounted to more than 10 trillion USD, whereas the total bank credit to firms is only 2.4 trillion USD. Corporate bond prices have also been shown to be tightly linked to real investments and economic activities (Philippon, 2009; Gilchrist and Zakrajšek, 2012). It is, therefore, crucial to understand the determinants of funding costs in the corporate bond market. Meanwhile, the long-term interest rate is one of the most important drivers of the prices of long-term fixed-income securities like corporate bonds. To gain a complete understanding of how long-term interest rates affect corporate bond yields, it is crucial to grasp not only the dynamics of the long-term rate itself but also the dynamics of credit spreads. Hence, this paper aims to answer the critical question of the connection between the long-term interest rate and corporate bond credit spreads.

First, I present novel facts on the comovement between the long-term interest rate and corporate bond credit spreads. Leveraging detailed microdata on corporate bond prices, I estimate the pass-through of the 10-year Treasury yield to corporate bonds with different credit ratings. Before the 2008 Financial Crisis, the long-term rate and credit spreads exhibited no significant associations. That is, changes in the long-term rate seemed to affect all corporate bonds equally. However, after the Financial Crisis, I document a strong negative relationship between the long-term rate and corporate bond credit spreads. When long-term rates are low, the yields of low-credit-rating bonds rise relatively to high-credit-rating bonds. In fact, the yields of bonds with the lowest ratings even increase in absolute terms when the long-term rate falls.

Contrary to conventional wisdom, where low interest rates encourage risk-taking and reduce risk premia, declines in the long-term interest rate are accompanied by increases in corporate bond credit spreads, even after controlling for the yield curve and detailed bond characteristics. Moreover, the impact is more significant on bonds with lower credit ratings. When the long-term rate declines, the credit spreads of non-investment-grade bonds increase significantly more than investment-grade bonds. The
bond price responses also generate large real effects on corporate bond issuance. In times of low long-term interest rates, the issuance of non-investment-grade corporate bonds drops relative to the issuance of investment-grade corporate bonds. The issuance to outstanding amount ratio by investment-grade firms increases by more than 1.5% relative to non-investment-grade firms in a 6-month period when the 10-year Treasury yield is 1% lower. The finding reveals large credit supply effects from risky firms.

High-frequency identifications around monetary policy announcements further confirm the findings. Following Hillenbrand (2023), I construct high-frequency shocks to the 10-year Treasury yield using yield movements around FOMC meetings. Using a local projection method, I find that 10-year Treasury yield shocks do not cause significant changes in bond credit spreads before the Financial Crisis. In contrast, positive Treasury yield shocks induce large negative credit spread responses after the Financial Crisis. For example, a 1% decrease in the 10-year Treasury yield around FOMC meetings leads to a 0.7% increase in the spread between single B corporate bonds and AAA corporate bonds.

Second, I trace this new negative comovement to the duration mismatch and bond holdings of life insurers, the largest institutional investor group of US corporate bonds. The business model of modern life insurers involves investing in fixed-income securities and issuing long-term annuity products. Before the Financial Crisis, life insurers appeared to be hedged against interest rate risk. Their equity value was largely shielded from fluctuations in the long-term rate, which suggests that their assets and liabilities had matching duration. However, as the economy entered a low-interest-rate environment after the Financial Crisis, life insurers are now subject to a large duration mismatch, and their market equity values became sensitive to the long-term rate. When the 10-year Treasury yield falls by 1%, the market equity of the life insurance sector falls by more than 5%.

The negative comovement between credit spreads and the long-term rate only exists in bonds with life insurance ownership and is more pronounced in bonds with higher life insurance ownership. Next, I provide causal evidence that higher life insurance ownership generates stronger comovement between credit spreads and the long-term rate. The first approach compares near-identical bonds with different life insurance
ownership by applying rich interacted fixed effects (Coppola, 2022). The results suggest that, despite sharing the same issuer and similar characteristics, bonds mainly owned by life insurers have reacted more strongly to the long-term rate after the Financial Crisis. In contrast, the dynamics of credit spreads do not depend on life insurance ownership before the Financial Crisis. To further sharpen the identification, I exploit a discontinuity in bond ownership structure stemming from mutual funds’ investment mandates (e.g., Li and Yu, 2023). Many bond mutual funds are “intermediate-term” and mandated to invest in bonds whose maturities are less than 10 years, resulting in a discontinuity in investor composition around the 10-year maturity threshold. Bonds with maturities slightly below 10 years are significantly less likely to be held by life insurers than bonds with maturities slightly above 10 years, as they face higher demand from mutual funds. I then find that the bonds slightly to the left of the cutoff are much less responsive to the 10-year Treasury yield. The results point to a channel through which the long-term interest rate affects corporate bond credit spreads — life insurers suffer from equity drawdowns following reductions in the long-term interest rate. Consequently, their risk-bearing capacity is lower, and they reduce their holdings of risky bonds. Furthermore, I show that the bond trading behavior of life insurers supports the duration mismatch hypothesis. Following declines in the 10-year interest rate, life insurers respond by reducing their demand for risky bonds, manifested in the data as fewer future purchases of risky corporate bonds.

Third, I develop an intermediary asset pricing model to illustrate the role of duration mismatch facing life insurers. In the model, life insurers hold corporate bonds and Treasuries as assets and issue annuities as liabilities. Life insurers face duration mismatch because the annuities they issue have a much longer duration than their assets. A no-arbitrage condition between the annuities and Treasuries pins down the term structure. Declines in the Treasury yield cause declines in the yield on annuities, which raise life insurers’ funding costs and lower their net worth. Life insurers are the main investors of corporate bonds, and their risk-bearing capacity affects equilibrium credit spreads. Life insurers are more averse to bonds with lower credit ratings as they carry greater default risk and regulatory costs. As a result, when the long-term Treasury yield is low, life insurers become less willing to hold risky bonds, so the equilibrium credit
spreads widen. Analytically, I prove the existence of a negative relationship between the long-term interest rate and corporate bond credit spreads under common assumptions. When matched to the empirically estimated duration mismatch of life insurers, the structural model can explain the majority of the observed comovement between the long-term interest rate and corporate bond credit spreads.

These results hold significant relevance currently, particularly due to the increasing popularity of monetary policies targeting long-term rates, including Quantitative Easing and Tightening (QE and QT). My findings suggest that QE and QT have large unintended consequences in corporate bond markets. QE is a policy aimed at boosting the economy by reducing long-term interest rates. However, it may have unintended consequences by heightening credit spreads, especially for companies with higher risk profiles. On the other hand, the tightening effects of QT might be dampened as higher long-term rates could depress credit spreads and generate favorable financial conditions for bond-issuing firms.

**Related Literature.** My results contribute to the extensive literature on corporate bond credit spreads. Following Fama and French (1993), many have modeled corporate bond yields using factor models (e.g., Gebhardt, Hvidkjaer and Swaminathan, 2005; Bao, Pan and Wang, 2011; Lin, Wang and Wu, 2011; Acharya, Amihud and Bharath, 2013; Bai, Bali and Wen, 2019; Kelly, Palhares and Pruitt, 2023). The factor approach typically views credit risk and the term structure as orthogonal factors in determining bond yields. In this paper, I show that the pricing of the two factors is interconnected, as the level of long-term interest rates could affect the pricing of credit risk through the balance sheets of life insurers. The model of Section 5 also connects to existing structural models on corporate bond credit risk (e.g., Merton, 1974; Black and Cox, 1976; Eom, Helwege and Huang, 2004; Schaefer and Strebulaev, 2008; Chen, Collin-Dufresne and Goldstein, 2009; Kuehn and Schmid, 2014; Feldhütter and Schaefer, 2018).

This paper also belongs to the burgeoning literature focusing on the role of institutional investors in the corporate bond market. My work is most closely connected to Coppola (2022) and Li and Yu (2023), who, in different contexts, also show that investor

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1See Huang and Shi (2021) for an overview of the literature on corporate bond returns.
composition matters for bond price dynamics. Using similar identification strategies, I show that life insurance ownership induces a negative comovement between credit spreads and the long-term interest rate after the Financial Crisis. A recent strand of the literature studies the role of mutual funds in liquidity disruptions in crises (e.g., Had-dad, Moreira and Muir, 2021; Falato, Goldstein and Hortaçsu, 2021; Jiang et al., 2022; Ma, Xiao and Zeng, 2022). In this paper, I instead focus on life insurers, the largest institutional investor group in the corporate bond market (Koijen and Yogo, 2023), to show that they are important for bond prices also in normal times. Recent works such as Bretscher et al. (2022) and Darmouni, Siani and Xiao (2022) use demand system approaches to analyze the equilibrium effects of institutional demand. In this paper, I deviate from the standard logit portfolio choices used in the demand system literature to focus on life insurers’ duration mismatch.

The focus of my paper echoes recent research on the investing behavior of life insurance companies (e.g., Koijen and Yogo, 2022; 2023; Chodorow-Reich, Ghent and Haddad, 2021; Ellul et al., 2022). Several studies, including Berends et al. (2013), Hartley, Paulson and Rosen (2016), Domanski, Shin and Sushko (2017), Ozdagli and Wang (2019), Koijen and Yogo (2022), and Huber (2022) have also shown that life insurers’ interest rate risk exposure changed after the Financial Crisis. I build on this finding and argue that the duration mismatch can significantly influence bond prices since life insurers are major investors in bond markets. Existing studies by Ellul, Jotikasthira and Lundblad (2011), Nanda, Wu and Zhou (2019), Girardi et al. (2021), Becker, Opp and Saidi (2022), and Murray and Nikolova (2022) have established that the trades of life insurers have potentially large price impacts on corporate bond prices. I confirm that life insurers can considerably influence bond prices in the context of how corporate bond yields respond to long-term interest rate fluctuations.

The approach of this paper connects to the literature on intermediary asset pricing, which emphasizes the role of the financial health of intermediaries on asset prices (e.g., Brunnermeier and Pedersen, 2009; He and Krishnamurthy, 2013, 2018; Adrian, Etula and Muir, 2014; He, Kelly and Manela, 2017; Haddad and Muir, 2021; Baron and Muir, 2022). My paper finds that the duration mismatch of life insurers, the largest intermediaries in the corporate bond market, significantly affects bond credit spreads.
Additionally, this paper contributes to the literature on the impact of monetary policy and interest rates on the financial system. Departing from existing works that focus on banks and loan supply (e.g., Kashyap and Stein, 2000; Jiménez et al., 2012; Jiménez et al., 2014; Abadi, Brunnermeier and Koby, 2023), I instead focus on life insurers and corporate bonds. I present evidence that a lower long-term interest rate significantly increases corporate bond credit spreads and depresses bond issuance by risky firms, which is distinct from the usual findings of the banking literature.

**Outline.** Section 2 describes data sources for the empirical analysis. Section 3 discusses evidence on the comovement between the long-term interest rate and corporate bond credit spreads. Section 4 investigates the role of life insurers in shaping the comovement. Section 5 builds an intermediary asset pricing model that accounts for the empirical findings. Section 6 concludes.

## 2 Data

In this paper, I combine data from multiple sources to assess the comovement between the long-term rate and corporate bond credit spreads and to investigate the significance of life insurers.

**The Long-term Interest Rate.** I use the US Treasury yield curve constructed by Liu and Wu (2021) at a daily frequency. In particular, I use the yield on 10-year US Treasury notes as the proxy for the long-term interest rate.

**Corporate Bonds.** I combine data from the Mergent Fixed Income Securities Database (Mergent FISD), the Trade Reporting and Compliance Engine (TRACE), and the WRDS Bond Returns for corporate bond prices, quantities, and characteristics. The dataset provides comprehensive coverage for US corporate bonds between 2000 and 2019. From Mergent FISD, I obtain information on the bond issuer, maturity, duration, credit ratings, outstanding amount, issuance date, coupons, transaction volume, and default history at a monthly frequency. The WRDS Bond Returns dataset also provides end-of-month transaction prices and yields extracted from TRACE. For any given month, I
focus on bonds with at least one observed transaction price.

Mergent FISD reports three “raw” credit ratings from Standard and Poor’s (S&P), Moody’s Analytics, and the Financial Industry Regulatory Authority (FINRA). For my analysis, I adopt the NAIC system that consolidates the three ratings into one and sorts them into six NAIC categories. The NAIC rating is the most relevant risk metric for insurance companies, as it determines the capital requirement for each bond. Bonds in NAIC 1 and NAIC 2 are investment-grade, while bonds in NAIC 3-6 are non-investment-grade. Table 1 replicates Table 2 in Becker and Ivashina (2015), which summarizes the 5-year default rate and capital requirement of each NAIC category. Corporate bonds with lower NAIC ratings have higher default rates and entail more stringent capital requirements.

<table>
<thead>
<tr>
<th>NAIC Category</th>
<th>Credit Ratings</th>
<th>Investment Grade</th>
<th>5-year Default Rate (1990-2010)</th>
<th>Capital Requirement</th>
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</thead>
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<tr>
<td>NAIC 1 (highest)</td>
<td>AAA, AA, A</td>
<td>✓</td>
<td>0.00%, 0.09%, 0.69%</td>
<td>0.3%</td>
</tr>
<tr>
<td>NAIC 2</td>
<td>BBB</td>
<td>✓</td>
<td>2.62%</td>
<td>0.96%</td>
</tr>
<tr>
<td>NAIC 3</td>
<td>BB</td>
<td>x</td>
<td>6.76%</td>
<td>3.39%</td>
</tr>
<tr>
<td>NAIC 4</td>
<td>B</td>
<td>x</td>
<td>8.99%</td>
<td>7.38%</td>
</tr>
<tr>
<td>NAIC 5</td>
<td>CCC</td>
<td>x</td>
<td>34.38%</td>
<td>16.96%</td>
</tr>
<tr>
<td>NAIC 6 (lowest)</td>
<td>CC, C, D</td>
<td>x</td>
<td>n.a.</td>
<td>19.50%</td>
</tr>
</tbody>
</table>

Table 1: The NAIC Rating System. This Table summarizes the characteristics of corporate bonds belonging to different NAIC categories. The data on the cumulative 5-year default rates and capital requirements are drawn from Becker and Ivashina (2015).

For part of my empirical analysis, I also use aggregate bond yield indices from the Intercontinental Exchange and bond credit default swaps (CDS) spreads from Markit IHS. I use the par spreads of credit default swaps with a 5-year tenor, which form the most liquid segment of the CDS market (e.g., Blanco, Brennan and Marsh, 2005).

Life Insurers. I obtain regulatory data on life insurers’ end-of-year bond holdings and long-term bond transactions from the National Association of Insurance Commissioners (NAIC). I examine the Schedule D information in life insurers’ regulatory reports to
The NAIC data also contains bond identifiers that allow me to match the bonds held and transacted by life insurers to those in Mergent FISD and WRDS Bond Returns. In addition to the NAIC data, I use data on the aggregate balance sheets of life insurers from the Financial Accounts of the United States and data on life insurers’ stock prices from the Center for Research in Security Prices (CRSP).

**Sample Period.** Throughout the paper, I separate my analysis into two time periods: 2000-2006 (before the Financial Crisis) and 2010-2019 (after the Financial Crisis). The sample dates back to January 2000, the date of the earliest observation in WRDS Bond Returns. I remove the Great Financial Crisis (2007-2009), which features large-scale fire sales and liquidity interruptions that potentially confounds the mechanism of interest. Similarly, I do not use the data after 2020 to avoid capturing the bond market disruptions during the Covid-19 Crisis and the high inflation that follows.

## 3 The Long-term Interest Rate and Bond Credit Spreads

In this section, I examine the comovement between the long-term interest rate and corporate bond credit spreads and contrast the findings before and after the 2008 Financial Crisis.

### 3.1 Pass-through of the Long-term Interest Rate

I begin by studying the pass-through of the 10-year Treasury yield in the cross-section of corporate bonds. I run the following regressions to estimate the pass-through

\[
y_{it} = \alpha_i + \sum_{k=1}^{6} \beta_k \cdot 1_{\{\text{NAIC} \, k\}} \cdot y_{t}^{(10)} + \Gamma \mathbf{X}_{it} + \epsilon_{it},
\]

where \(y_{it}\) is the yield of bond \(i\) at time \(t\), \(y_{t}^{(10)}\) is the 10-year Treasury yield, \(\alpha_i\) are bond fixed effects, and \(\mathbf{X}_{it}\) are additional controls. Here I control for bond characteristics such as bond size (outstanding amount), liquidity (trading volume), maturity, duration,

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\(^2\)See https://content.naic.org/sites/default/files/ASB-PCA-22_0.pdf for the structure and content of the dataset.
credit ratings, coupon amount, and coupon frequency, as well as the recent default rate of each NAIC category.

The regression coefficient $\beta_k$ measures the pass-through rate of the 10-year Treasury yield to the yield of NAIC $k$ corporate bonds. Intuitively, $\beta_k$ measures the average response of the yields of NAIC $k$ bonds when the 10-year Treasury yield increases by one percentage point. Figure 1 shows the estimates of $\beta_k$ for the sample before the Financial Crisis (2000-2006) and the sample after the Financial Crisis (2010-2019).

After the Financial Crisis, there is a strong relationship between credit ratings and the pass-through of the long-term interest rate. The yields of the safest bonds (i.e., NAIC 1 and 2) move strongly with the 10-year Treasury yield. As the credit rating worsens, the sensitivity to the long-term rate diminishes and eventually reverses for bonds with the lowest credit ratings (NAIC 5 and 6). The effects are large, especially for bonds in NAIC 5 and 6, whose yields increase by much more than 1% when the 10-year Treasury yield declines by 1%. Accordingly, the spreads between bonds with low and high credit ratings widen when the 10-year Treasury yield is low.

In contrast, the relationship is much weaker before the Financial Crisis. Before the Crisis, bonds in NAIC 1 and 2 have a strong positive comovement with the 10-year Treasury yield. However, the responses of low-credit-rating bonds are much smaller and sometimes not statistically different from those in NAIC 1 and 2.

Overall, the results indicate a significant change in the comovement between the long-term rate and corporate bond yields around the Financial Crisis.

### 3.2 Credit Spread Responses to the Long-term Rate

Next, I focus on the credit spreads in the cross-section of corporate bonds. To this end, I analyze the spreads between bonds with lower ratings (NAIC $k$, $k \geq 2$) and the highest credit rating (NAIC 1). Relative to the empirical specification in regression (1), I further include maturity-time fixed effects $\alpha_{T(i),t}$,

$$y_{it} = \alpha_i + \alpha_{T(i),t} + \sum_{k=2}^{6} \beta_k \cdot 1_{\{\text{NAIC } k\}} \cdot y^{(10)}_t + \Gamma X_{it} + \varepsilon_{it}. \quad (2)$$

To construct the maturity-time fixed effects, I sort bonds into small maturity segments with a 1-year width each month and interact the maturity dummies with the time vari-
Figure 1: **Pass-through of the 10-year Treasury yield.** This figure plots the coefficients estimated from regression (1), controlling for the trading volume, outstanding amount, maturity, duration, credit ratings, coupon amount, and coupon frequency of each bond, and the recent default rate of each NAIC category. Both corporate bond yields and the Treasury yield are in percentage points. The top panel shows results for the post-Crisis sample, while the bottom panel shows results for the pre-Crisis sample. The statistical significance is based on standard errors clustered at the NAIC category and year-month levels, \(^* p < 0.10\), \(^* * p < 0.05\), \(^* * * p < 0.01\).
able. The fixed effects thus control for the maturity differences across each NAIC category\(^3\) and variations in the yield curve over time. Additionally, the fixed effects absorb one NAIC category for any given month, which I normalize as NAIC 1. Hence, the coefficient \(\beta_k\) (for \(k \geq 2\)) measures the average response that changes in the 10-year Treasury yield induce in the *spreads* between NAIC \(k\) bonds and NAIC 1 bonds. A negative coefficient indicates that credit spreads move in opposite directions as the long-term interest rate.

**Figure 2** plots the estimated coefficients and delivers one of the main results of this paper. In the post-Crisis sample, corporate bond credit spreads fall when the 10-year Treasury yield increases. The result is significant for all NAIC categories and is stronger for lower ratings. To understand the significance of the results, it is useful to consider the following decomposition of bond yields

\[
y_{t,\text{NAIC}k} = y_{t,\text{NAIC}1} + (\text{Credit Spread})_{t,\text{NAIC}k}.
\]

The effect of the long-term rate on total bond yields depends on (1) how it affects the safest segment of the bond market (yields of NAIC 1 bonds) and (2) how it affects credit spreads relative to NAIC 1. In **Section 3.1**, I show that NAIC 1 bond yields comove positively with the 10-year Treasury yield, with a pass-through coefficient of about 0.53 after the Financial Crisis. For safer bonds (NAIC 2, 3, and 4), the effect on credit spreads partially offsets the changes in NAIC 1 yields, making bond yields less sensitive to the 10-year Treasury yield. The effects are much larger for the riskiest bonds. For example, when the 10-year Treasury yield increases by 25 basis points, the yields of CCC corporate bonds (NAIC 5) fall by 86 basis points relative to corporate bonds rated A or better (NAIC 1), which is large enough to fully offset the increase in NAIC 1 yields and lower the NAIC 5 yields in absolute terms. As shown in **Figure 1**, the yields of NAIC 5 and 6 bonds move in opposite directions as the 10-year Treasury yield. Surprisingly, increases in the long-term interest rate lower the funding costs of the riskiest firms.

It is also worth noting that the effects on credit spreads were absent before the Financial Crisis. In the sample before 2007, credit spreads had very small and sometimes insignificant responses to the 10-year Treasury yield. This implies that the comovement between the long-term interest rate and credit spreads only emerged after the Crisis.

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\(^3\)It is important to control for maturity as riskier bonds tend to be of shorter maturity.
Figure 2: **Credit Spread Responses to Changes in the Long-term Rate.** This figure plots the coefficients estimated from regression (2), controlling for the trading volume, outstanding amount, maturity, duration, credit ratings, coupon amount, and coupon frequency of each bond, and the recent default rate of each NAIC category. Both corporate bond yields and the Treasury yield are in percentage points. The top panel shows results for the post-Crisis sample, while the bottom panel shows results for the pre-Crisis sample. The statistical significance is based on standard errors clustered at the NAIC category and year-month levels, *p < 0.10, **p < 0.05, ***p < 0.01.
Figure A.1 and Figure A.2 in the Appendix visualize the time series of the 10-year Treasury yield and various corporate bond credit spreads. The correlation pattern supports the conclusion of this Section. There exists a strong negative correlation between corporate bond credit spreads and the 10-year Treasury yield after the Financial Crisis but not before the Financial Crisis.

3.3 The Long-term Rate and Bond Issuance

I further show that the effects of the long-term interest rate on credit spreads have considerable real impacts on bond issuance. It has been argued that primary market bond prices (i.e., prices at issuance) are highly correlated to secondary market conditions (e.g., Coppola, 2022; Flanagan, Kedia and Zhou, 2019). Therefore, the comovement between the long-term rate and corporate bond credit spreads documented in Section 3.2 likely also affects firms’ incentives to issue new bonds.

To investigate the comovement between the long-term rate and corporate bond issuance, I aggregate new bond issuance for each NAIC category in Mergent FISD. I then estimate the following empirical specification

\[
\frac{\text{Issuance}_{k,t}^{(6m)}}{\text{Outstanding}_{k,t}} = \alpha_k + \alpha_t + \sum_{k=2}^{6} \beta_k \cdot 1_{\text{NAIC } k} \cdot y_t^{(10)} + \Gamma X_{kt} + \varepsilon_{kt},
\]

where \( \text{Issuance}_{k,t}^{(6m)} \) is the total NAIC \( k \) issuance in the 6-month period between month \( t + 1 \) and month \( t + 6 \), \( \text{Outstanding}_{k,t} \) is the total outstanding amount of NAIC \( k \) bonds at the end of the month \( t \), \( y_t^{(10)} \) is the 10-year yield at the end of the month \( t \), and the controls \( X_{kt} \) include the average maturity of new issues and the recent default rates of each NAIC category. The rating fixed effects \( \alpha_k \) capture the steady state differences in the growth rates of individual NAIC categories. The time fixed effects \( \alpha_t \) capture aggregate fluctuations in bond issuance.

I consider two specifications — one with the time fixed effects \( \alpha_t \) and one without. When \( \alpha_t \) is not imposed, the coefficient \( \beta_k \) captures the effect of the 10-year Treasury yield on the amount of NAIC \( k \) bond issuance. The issuance of NAIC \( k \) bonds increases by a \( \beta_k \) fraction of the current outstanding in the next 6 months when the 10-year Treasury yield increases by 1%. When \( \alpha_t \) is imposed, the fixed effects absorb the effect on
NAIC 1 issuance, so the coefficient $\beta_k$ measures how the 10-year Treasury yield affects the difference in issuance between NAIC $k$ and NAIC 1. The issuance-to-outstanding ratio of NAIC $k$ increases by $\beta_k$ relative to NAIC 1 when the 10-year Treasury yield increases by 1%.\(^4\)

Table 2 contains the estimated coefficients from regression (3). The first two columns report the results after the Financial Crisis. The first column suggests that increases in the 10-year Treasury yield significantly depress the issuance of NAIC 1 bonds. The effect is weaker for NAIC 2 and is reversed for NAIC 3-6. The second column shows that increases in the 10-year Treasury yield boost the issuance of NAIC 2-6 bonds relative to NAIC 1 bonds. Following a 1% increase in the long-term interest rate, the issuance of non-investment-grade (NAIC 3-6) bonds grows by more than 1.5% relative to the issuance of NAIC 1 bonds. The results suggest that the long-term interest rate could potentially alter the composition of the corporate bond market. Investment-grade bonds make up for a larger share of total new issuance when the long-term interest rate is low. After the Financial Crisis, the US economy entered a sustained period of low interest rates accompanied by a large bond market expansion. Consistent with my findings, the post-Crisis bond market expansion was concentrated in safe (investment-grade) firms (e.g., Mota, 2020).

In contrast, the issuance differences are not correlated with the long-term interest rate before the Financial Crisis. It is expected since the long-term interest rate affected all corporate bonds equally during that period, as demonstrated in Section 3.1.

3.4 High-frequency Evidence: FOMC Announcements

Section 3.1 and Section 3.2 discussed the unconditional comovements between the long-term interest rate and corporate bond credit spreads. In this section, I strengthen the evidence by showing identified evidence on the impact of the long-term interest rate on bond credit spreads using high-frequency shocks around FOMC meetings. A recent study by Hillenbrand (2023) documents that a short window around FOMC meetings explains the majority of the movements in the long-term rate for the past 30 years. The

\(^4\)The 10-year Treasury yield is highly persistent (e.g., Caporale, Gil-Alana and Yaya, 2022). The current 10-year Treasury yield has strong predictive power for the future path of the 10-year Treasury yield.
Table 2: Bond Issuance Responses to the Long-term Interest Rate. This figure plots the coefficients estimated from regression (3), controlling for the average maturity of new issues and the recent default rates of each NAIC category. The first two columns show results for the post-Crisis sample, while the last two columns show results for the pre-Crisis sample. Both the responsible variable and the 10-year Treasury yield are in percentage points. The statistical significance is based on standard errors clustered at the NAIC category and year-month levels, ∗p < 0.10, ∗∗p < 0.05, ∗∗∗p < 0.01.

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<th>NAIC</th>
<th>2010-2019</th>
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<td>(1)</td>
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</tr>
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<td>NAIC 4-6</td>
<td>0.224</td>
<td>1.560***</td>
</tr>
<tr>
<td></td>
<td>[1.897]</td>
<td>[1.672]</td>
</tr>
</tbody>
</table>

| NAIC FE | ✓ | ✓ | ✓ | ✓ |
| Time FE  | ✓ | ✓ |
| $R^2$    | .465 | .759 | .681 | .847 |

The potential explanation is that FOMC meetings disseminate relevant information for the long-term interest rate. Inspired by Hillenbrand (2023), I construct shocks to the 10-year Treasury yield as the changes in the yield in a 2-day window around FOMC meetings,

$$\Delta y_{t}^{(10)}|_{\text{FOMC}} = y_{t+1}^{(10)} - y_{t-1}^{(10)},$$

where $t$ is an FOMC announcement day. Using a local projection method (Jordà, 2005), I then estimate the impulse responses of corporate bond credit spreads to the high-frequency 10-year Treasury yield shocks. The regressions are as follows

$$\text{Spread}_{t+h}^{k} - \text{Spread}_{t-1}^{k} = \alpha_{h} + \beta_{h} \left( \Delta y_{t}^{(10)}|_{\text{FOMC}} \right) + \text{lagged variables} + \varepsilon_{t,h}. \quad (4)$$

Here the life-hand-side variable $\text{Spread}_{t}^{k}$ is constructed as the difference between the bond yield index for rating $k$ and the bond yield index for the AAA rating. The coef-
icient $\beta_k$ measures the cumulative response of $\text{Spread}^k_t$ to a 1% positive innovation in the 10-year Treasury yield at a horizon of $h$ trading days.

Figure 3 and Figure 4 plot the impulse response functions estimated from the local projections (4) for the post-Crisis sample and the pre-Crisis sample, respectively. After the Financial Crisis, positive shocks to the 10-year Treasury yield led to large and significant declines in the credit spreads between AAA bonds and bonds with lower credit ratings. For example, a 1% increase in the 10-year Treasury yield depresses the spread between single B and AAA bonds by more than 1% at a 10-day horizon. Nevertheless, similar shocks to the 10-year Treasury yield produced statistically insignificant or even the opposite responses before the Crisis. The results suggest that there was a shift in the transmission of policy shocks around the Financial Crisis.

The results so far focus on credit spreads relative to AAA bonds. Figure A.3 in the Appendix replaces the spreads relative to AAA bonds with the spreads relative to US Treasury securities and finds similar impulse responses. Figure A.4 instead estimates the local projections directly on the yield indices for different credit ratings. The yield of AAA bonds exhibits a persistently positive dependence on the 10-year Treasury yield, while yields of other investment-grade bonds (AA, A, BBB) are less sensitive. Consistent with the findings of Section 3.1, the yields of non-investment-grade bonds (BB and lower) seem to move in the opposite direction as the 10-year Treasury yield.

### 3.5 Discussion on the Mechanism

In this section, I document a negative comovement between the long-term interest rate and corporate bond credit spreads after the Financial Crisis — credit spreads rise when the 10-year Treasury yield is low. The results might seem counterintuitive relative to the standard macro-finance literature, where low interest rates lower risk premia by enhancing the balance sheets of financial intermediaries or encouraging reaching-for-yield behaviors. While the standard theory has been proven true in the context of bank lending (e.g., Kashyap and Stein, 2000; Jiménez et al., 2014; Whited, Wu and Xiao, 2021), I show there exists an opposite effect in the corporate bank market.

The favored explanation this paper proposes is the impact of life insurers’ duration mismatch. In Section 4.1, I empirically document a shift in the life insurance sector’s
Figure 3: **Impulse Responses of Credit Spreads (2010-2019).** The figure plots the cumulative responses of credit spreads to a 1% increase in the 10-year Treasury yield and 95% confidence intervals based on Newey-West standard errors. The maximum length of lags is 30 trading days.

Figure 4: **Impulse Responses of Credit Spreads (2000-2006).** The figure plots the cumulative responses of credit spreads to a 1% increase in the 10-year Treasury yield and 95% confidence intervals based on Newey-West standard errors. The maximum length of lags is 30 trading days.
duration mismatch and investigate their contribution to the relationship between the long-term interest rate and credit spreads. Under the new duration mismatch, life insurer suffers from equity drawdowns when the long-term rate declines, which increase their portfolio exposure to corporate bonds. Since life insurers are the largest investor group in the bond market, elevations in their effective risk aversion lead to higher equilibrium corporate bond credit spreads.

While life insurers are important for this negative comovement, there exist other potential channels through which the long-term interest rate affects risk premia in the bond market. For example, pension funds have a balance sheet structure similar to the life insurers, which makes them susceptible to interest rate fluctuations too. The long-term interest rate itself could also contain information about the future path of the economy. If a higher long-term interest rate reflects stronger future economic growth, it could also reduce the perceived risk in corporate bonds, contributing to lower credit spreads. In Section 5, I analyze a structural model of the corporate bond market to quantify the fraction of the comovement explained by life insurers. Then the unexplained fraction is potentially due to the other mechanisms discussed above.

4 The Role of Life Insurers

Next, I turn to the potential channel through which the long-term interest rate negatively affects corporate bond credit spreads — life insurers’ duration mismatch. As documented in Koijen and Yogo (2023), life insurers are the largest investor group in corporate bonds and own more than 30% of all corporate bonds in the US as of 2023.  

4.1 Duration Mismatch

Modern life insurers issue various life insurance and annuity products while investing primarily in fixed-income markets. For example, variable annuities, which are long-term mutual fund products with minimum return guarantees, have now become the largest component of life insurers’ liabilities (Koijen and Yogo, 2022). Maturity transformation is a key component of life insurers’ operations, as they invest in fixed-income

---

5 Figure A.5 plots the life insurers’ share in the corporate bond market.
securities (e.g., corporate bonds) and turn them into longer-term liabilities (e.g., variable annuities). Unlike banks that turn long-term loans into short-term deposits, the maturity transformation of life insurers takes the opposite direction. Hence, life insurers’ market equity could be hurt when the long-term interest rate is low.

Table 3 summarizes the balance sheet structure of the US life insurance sector. Life insurers’ assets are predominantly fixed-income debt securities and mutual fund shares that are ultimately also invested in fixed-income assets. Corporate bonds are an important asset class for life insurers as they make up 80% of all the debt securities they hold. On the liability side, life insurers raise funding mostly by selling life insurance and annuities, which typically have a longer maturity and duration than corporate bonds.

<table>
<thead>
<tr>
<th>Financial Assets ($ tn)</th>
<th>Liabilities ($ tn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term Assets</td>
<td>0.20</td>
</tr>
<tr>
<td>Debt Securities</td>
<td>4.43</td>
</tr>
<tr>
<td>– Corporate Bonds</td>
<td>–3.56</td>
</tr>
<tr>
<td>Loans &amp; Equities</td>
<td>1.54</td>
</tr>
<tr>
<td>Mutual Fund Shares</td>
<td>1.70</td>
</tr>
<tr>
<td>Other Financial Assets</td>
<td>1.55</td>
</tr>
<tr>
<td>Total</td>
<td>9.42</td>
</tr>
<tr>
<td>Life Insurance Reserves</td>
<td>2.25</td>
</tr>
<tr>
<td>Annuity Reserves</td>
<td>3.79</td>
</tr>
<tr>
<td>Other Liabilities</td>
<td>2.34</td>
</tr>
<tr>
<td>Total</td>
<td>8.38</td>
</tr>
</tbody>
</table>

Table 3: **The Balance Sheets of the Life Insurance Sector.** This table summarizes the main financial assets and liabilities of life insurers in the US. The data is from the Financial Accounts of the United States at 2020 Q4.

I then estimate the exposure of life insurers’ market equity to the 10-year Treasury yield. In particular, I run the following regressions

\[ \text{ExcessReturn}_t = \alpha + \beta \Delta y_{10}^{(t)} + \text{Controls} + \varepsilon_t. \]  

Here ExcessReturn\(_t\) is the excess stock return of the life insurance sector in day \(t\), and \(\Delta y_{10}^{(t)}\) is the change in the 10-year Treasury yield in day \(t\). The coefficient \(\beta\) measures the sensitivity of life insurers’ market equity to changes in the 10-year Treasury yield. If the duration of life insurers’ liabilities exceeds their assets, the coefficient \(\beta\) should be positive, as higher interest rates lower the value of their liabilities more than their assets and thereby boost the value of their equity. Therefore, \((-\beta)\) can also be interpreted as
an estimate of the duration of life insurers’ market equity, which is defined as \( D_E = -\frac{\partial E_t}{\partial y_t^{(10)}} \) \((E_t\) is the market equity of life insurers in day \( t\)). A positive estimate of \( \beta \) then indicates that life insurers’ equity has a negative duration (e.g., Ozdagli and Wang, 2019; Kojien and Yogo, 2022).

Table 4 contrasts life insurers’ exposure to the 10-year Treasury yield before and after the Financial Crisis. Before the Financial Crisis, the stock returns of the life insurance sector did not seem to be affected by the long-term interest rate. It implies that life insurers were largely hedged against interest rate risk. However, the estimated \( \beta \) is significantly away from zero in the post-Crisis period. The estimated coefficient of 5.32 suggests that life insurers’ equity value falls by more than 5.3% if the long-term interest rate falls by 1%, so life insurers face severe duration mismatch after the Financial Crisis.

<table>
<thead>
<tr>
<th>Dep. Var.: ExcessReturn(_t)</th>
<th>2000-2006</th>
<th>2010-2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta y_t^{(10)} )</td>
<td>-0.200</td>
<td>5.315***</td>
</tr>
<tr>
<td></td>
<td>[-0.368]</td>
<td>[6.833]</td>
</tr>
<tr>
<td>S&amp;P 500 Return</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>( \Delta y_t^{(1m)} )</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Observations</td>
<td>1746</td>
<td>2497</td>
</tr>
</tbody>
</table>

Table 4: **Life Insurers’ Duration Mismatch.** This table shows the coefficients estimated from regression (5), controlling for the market return and changes in the one-month Treasury yield. The first column shows the result for the pre-Crisis sample, while the second column shows the result for the post-Crisis sample. Both the excess return and the 10-year Treasury yield are in percentage points. The statistical significance is based on robust standard errors, *\( p < 0.10 \), **\( p < 0.05 \), ***\( p < 0.01 \).

Figure A.6 in the Appendix shows the evolution of life insurers’ duration mismatch over time. In particular, the figure plots the two-year rolling estimates of \( \beta \). Consistent with existing findings (e.g., Hartley, Paulson and Rosen, 2016; Ozdagli and Wang, 2019; Huber, 2022), the estimated exposure to interest rate risk is small and insignificant from zero before the Financial Crisis, whereas large and persistent deviations from zero are found after the Financial Crisis. Overall, the results suggest that life insurers’ duration mismatch increased dramatically after the Financial Crisis.
Figure 5 plots the market leverage ratio of the life insurance sector against the 10-year Treasury yield. Consistent with the previous findings, life insurers become more levered when the 10-year Treasury yield is low, as their liabilities become more expensive and their equity shrinks.

![Figure 5: Life Insurers' Market Leverage](image)

**Figure 5: Life Insurers’ Market Leverage.** The figure plots the market leverage ratio of the US life insurance sector and the 10-year Treasury yield. The market leverage ratio is defined as the “fair” value of their liabilities (from Compustat) divided by their market equity value.

**The Source of Duration Mismatch.** In the rest of this paper, I will be neutral on the cause of the shift in life insurers’ duration mismatch. Nevertheless, the existing literature typically attributes the shift to lower interest rates after the Financial Crisis. To illustrate this point, we can write life insurers’ equity as $E = A - L$, where $A$ is assets, $L$ is liabilities, and $\ell = L/E$ is the leverage ratio. The duration of equity is then $D_E = (AD_A - LD_L)/E = (1 + \ell)D_A - \ell D_L$. Before the Crisis, life insurers were hedged against interest rate risk by choosing $D_A \approx [\ell/(1 + \ell)]D_L$, so that $D_E \approx 0$. Meanwhile, the assets and the liabilities both have a positive convexity as lower interest rates increase bond duration,

$$C_A := -\frac{\partial D_A}{\partial y_i^{(10)}} > 0, \quad C_L := -\frac{\partial D_L}{\partial y_i^{(10)}} > 0.$$
Crucially, the convexity of life insurers’ liabilities is greater than the convexity of their assets ($C_L > C_A$), meaning that $D_L$ rises faster than $D_A$ when interest rates fall. As a result, $D_E$ became negative in the low interest environment after the Crisis. Furthermore, there exist frictions that prevent life insurers from increasing their asset duration $D_A$ to close the duration gap. Domanski, Shin and Sushko (2017) and Greenwood and Vissing-Jorgensen (2018) argue that large-scale portfolio rebalancing of life insurers towards longer-term assets puts downward pressure on the long-term interest rate, which could further exacerbate the duration mismatch. Ozdagli and Wang (2019) emphasize the role of portfolio adjustment frictions linked to the cost of large bond trades. Koijen and Yogo (2021) discussed several other reasons why life insurers do not fully hedge their interest rate exposure, including market incompleteness (i.e., the scarcity of long-term assets and options), risk-shifting motives, and regulatory distortions. In particular, Huber (2022) and Sen (2022) argue that the statutory reserve regulation imposed on life insurers does not properly capture the interest rate risk and distorts life insurers’ hedging incentives.

4.2 Life Insurers and Bond Prices

I further show that life insurers play an important role in shaping the comovement between the long-term interest rate and corporate bond credit spreads. Section 3.1 illustrates that the long-term interest rate has heterogeneous impacts on the cross-section of corporate bonds after the Financial Crisis. If life insurers’ duration mismatch is the main channel through which the long-term interest rate affects credit spreads, we should expect the pattern to be more pronounced in bonds owned by life insurers. In this Section, I recover the fraction of each bond owned by life insurers from NAIC regulatory reports and study the role life insurance ownership in shaping the results of Section 3.1 and Section 3.2.

---

6One likely explanation is that life insurers’ liabilities have a longer maturity than their assets, as the convexity of an asset typically increases in its maturity. It could also be because the embedded options in some of life insurers’ variable annuity liabilities are less exercised when interest rates are low (e.g., Ozdagli and Wang, 2019; Koijen and Yogo, 2022).

7For more examples of regulatory distortions in the insurance sector, see also Lee, Mayers and Smith (1997), Ellul, Jotikasthira and Lundblad (2011), Becker, Opp and Saidi (2022), and Ellul et al. (2022).
The Pass-through of the Long-term Interest Rate. To examine how life insurers affect the pass-through of the long-term interest rate, I modify regression (1) in Section 3.1 as

\[ y_{it} = \alpha_i + \sum_{k=1}^{6} \left( \beta_k^0 + \beta_k^1 \cdot 1_{\{\text{insurer ownership}\}} \right) \cdot 1_{\{\text{NAIC} k\}} \cdot y_{(10)}^t + \Gamma X_{it} + \epsilon_{it}. \]  

(6)

The pass-through coefficients are allowed to differ between bonds with no life insurance ownership and bonds with positive life insurance ownership. \( \beta_k^0 \) measures the pass-through of the 10-year Treasury yield to NAIC \( k \) bonds not held by life insurers, while \( \beta_k^1 \) measures the pass-through to NAIC \( k \) bonds that are held by life insurers.

Figure 6 plots the estimated coefficients from regression (6) for the post-Crisis period. Indeed, the relationship between pass-through and credit ratings in Figure 1 is only present in bonds with positive life insurance ownership. Bonds with no life insurance ownership exhibit either no significant pass-through (NAIC 1-4) or the opposite pass-through compared to Figure 1 (NAIC 5-6). Moreover, the pass-through estimates for bonds with life insurance ownership have comparable magnitudes to those shown in Figure 1. Thus, the empirical findings of Section 3.1 could largely be driven by life-insurer-owned bonds.

Credit Spread Responses. I next study the contribution of life insurers to the findings of Section 3.2, which show that corporate bond credit spreads respond negatively to changes in the 10-year Treasury yield after the Financial Crisis. To test the role of life insurers, I estimate the following empirical specification based on regression (2)

\[ y_{it} = \left( \beta_2 \cdot 1_{\{\text{NAIC} 2\}} + \beta_3 \cdot 1_{\{\text{NAIC} 3-6\}} \right) y_{(10)}^t + \left( \gamma_2 \cdot 1_{\{\text{NAIC} 2\}} + \gamma_3 \cdot 1_{\{\text{NAIC} 3-6\}} \right) \phi_{it}^{\text{Ins}} y_{(10)}^t + \text{Interacted FE} + \Gamma X_{it} + \epsilon_{it}. \]  

(7)

Here \( \phi_{it}^{\text{Ins}} \) is the fraction of bond \( i \) held by life insurers. Importantly, I include an interaction term between a bond’s life insurer ownership share and the 10-year Treasury yield \( \phi_{it}^{\text{Ins}} y_{(10)}^t \). The coefficient \( \gamma_k \) then measures how the comovement between the long-term interest rate and credit spreads depends on a bond’s life insurer ownership share. In particular, \( \gamma_k < 0 \) means the credit spread of bond \( i \) responds more negatively to the 10-year Treasury yield when it is held more by life insurers.
Figure 6: **Pass-through by Life Insurance Ownership.** This figure plots the coefficients estimated from regression (6) for the period of 2010-2019, controlling for the trading volume, outstanding amount, maturity, duration, credit ratings, coupon amount, and coupon frequency of each bond, and the recent default rate of each NAIC category. Both corporate bond yields and the Treasury yield are in percentage points. The top panel shows estimates for $\beta_k^1$, while the bottom panel shows estimates for $\beta_k^0$. The statistical significance is based on standard errors clustered at the NAIC category and year-month levels, $^* p < 0.10$, $^{**} p < 0.05$, $^{***} p < 0.01$. 
To strengthen the identification, I apply interactive fixed effects as in Coppola (2022). The goal is to compare bonds with different investor bases that are otherwise identical. In the regression, I apply the following interacted fixed effects

\[ \text{Time} \times \text{Issuer} \times \text{Rating} \times \text{CDS Spread} \times \text{Size} \times \text{Duration}. \]

That is, I compare the yields of bonds issued by the same firm, having the same rating, similar CDS spreads, size, and duration. To control for differences in credit risk, I compare bonds with the same credit rating and credit default swap (CDS) spread. The CDS spread of a bond is the market price investors pay to insure themselves against the bond’s future default risk. It is known that life insurers prefer bonds with higher credit ratings but also select relatively riskier bonds (e.g., bonds with higher CDS spreads) within each credit rating (Becker and Ivashina, 2015). The rating-by-CDS-spread interacted fixed effects can potentially capture most of the bond selection pattern of life insurers. I further interact the fixed effects with other bond characteristics such as sizes (issuance amount, 10 million USD segments) and duration (1-year segments). As argued by Coppola (2022), the remaining variations in life insurance ownership could be attributed to idiosyncratic shocks in the primary market and are plausibly orthogonal to fundamentals. Lastly, I merge all non-investment-grade categories (NAIC 3-6) to have a larger sample size because NAIC 3-6 are individually small categories (especially NAIC 5-6) with relatively few identifying bonds after applying the interactive fixed effects.

Table 5 shows the estimated coefficients from regression (7). After the Financial Crisis, life insurance ownership greatly amplifies the responses of bond credit spreads to the long-term interest rates, even when we focus on otherwise almost identical bonds. In response to a 1% increase in the 10-year Treasury yield, the credit spreads of NAIC 2 (BBB) bonds entirely held by life insurers fall by 9.81 basis points more than comparable bonds that life insurers do not own. The difference is much larger (2.58%) for non-investment-grade (NAIC 3-6) bonds. In contrast, life insurers’ bond ownership also had small and statistically insignificant impacts on the comovement between the long-term interest rate and bond credit spreads before the Financial Crisis. The impact
that life insurers have on credit spread responses has changed at the same time as their duration mismatch.

<table>
<thead>
<tr>
<th></th>
<th>2000-2006</th>
<th>2010-2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma_2 )</td>
<td>-0.0551*</td>
<td>-0.0981***</td>
</tr>
<tr>
<td></td>
<td>[-2.545]</td>
<td>[-4.732]</td>
</tr>
<tr>
<td>( \gamma_{3-6} )</td>
<td>-0.188</td>
<td>-2.580**</td>
</tr>
<tr>
<td></td>
<td>[-1.363]</td>
<td>[-3.838]</td>
</tr>
<tr>
<td>Interacted FE</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.946</td>
<td>.64</td>
</tr>
<tr>
<td>Identifying Bonds</td>
<td>391</td>
<td>833</td>
</tr>
</tbody>
</table>

Table 5: The Role of Life Insurer Holdings. This table shows the coefficients estimated from regression (7), controlling for interactive fixed effects, the trading volume, coupon amount, and coupon frequency for each bond. The first column shows the result for the pre-Crisis sample, while the second column shows the result for the post-Crisis sample. The statistical significance is based on standard errors clustered at the NAIC category and year-month levels, * \( p < 0.10 \), ** \( p < 0.05 \), *** \( p < 0.01 \).

4.3 Regression Discontinuity Design

To further sharpen the identification, I utilize an exogenous discontinuity in investor composition stemming from mutual funds’ investment mandates (e.g., Li and Yu, 2023). Bai, Li and Manela (2023) and Li and Yu (2023) document that a large fraction of corporate bond funds are “intermediate-term” and are mandated to only invest in bonds whose maturity is less than 10 years. For a bond with a maturity greater than 10 years at issuance, it will experience a surge in demand from mutual funds once it ages to the point where its maturity drops below 10 years. As a result, the bond’s ownership by other investors, such as life insurers, jumps downward.

Figure 7 visualizes the discontinuity in life insurers’ ownership share around the maturity threshold of 10 years and a quarter. Indeed, we observe a large discontinuous jump in life insurers’ ownership shares at the maturity threshold. Bonds whose maturity falls below the threshold are much less likely to be held by life insurers.\(^8\)

\(^8\)The actual maturity cutoff for the discontinuity (10.25 years) seems to be slightly greater than 10
Figure 7: **Discontinuity in Investor Composition.** This figure shows a bin scatter plot of corporate bonds’ life insurance ownership share (\%) and their maturity. The vertical line indicates the maturity threshold of 10.25 years. The figure also shows the best-fit second-order polynomials for observations on each side of the threshold.

I further test the existence of the discontinuity using both OLS regressions and the robust bias-correction method of Calonico, Cattaneo and Titiunik (2014). In the OLS method, I regress the life insurer ownership share on a dummy variable indicating whether a bond’s maturity is above the threshold \( 1\{\text{maturity}_{it} \geq c\} \) where \( c = 10.25 \).

\[
\varphi_{it}^{\text{Ins}} = \alpha + \beta \cdot 1\{\text{maturity}_{it} > c\} + \Gamma X_{it} + \varepsilon_{it}.
\]

In the robust bias-correction method, I treat the problem as a sharp regression discontinuity design (RDD), where the treatment status is determined by \( 1\{\text{maturity}_{it} \geq c\} \) and the outcome variable is the life insurer ownership share.

Table 6 summarizes the effect of the maturity threshold on life insurer shares estimated using different methods. All results imply a strong discontinuity in investor composition at the maturity cutoff. The life insurers’ ownership share is around 4\% years. A likely explanation is mutual funds’ window dressing behavior, meaning that mutual funds only need to comply with their mandates at the end of each quarter when they disclose their bond holdings (e.g., Morey and O’Neal, 2006; Agarwal, Gay and Ling, 2014). Therefore, mutual funds could invest in bonds with a maturity between 10 and 10.25 years even if it is mandated to invest in bonds with maturity less than 10 years.

---

28
higher for bonds whose maturity is slightly above the cutoff.

<table>
<thead>
<tr>
<th>Method</th>
<th>$\beta$</th>
<th>$p$-value</th>
<th>[95% Conf. Interval]</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLS</td>
<td>4.88</td>
<td>0.000</td>
<td>[4.08, 5.69]</td>
</tr>
<tr>
<td>RDD, Conventional</td>
<td>3.93</td>
<td>0.003</td>
<td>[1.35, 6.51]</td>
</tr>
<tr>
<td>RDD, Bias-corrected</td>
<td>4.27</td>
<td>0.001</td>
<td>[1.69, 6.85]</td>
</tr>
<tr>
<td>RDD, Bias-corrected, Robust</td>
<td>4.27</td>
<td>0.005</td>
<td>[1.32, 7.22]</td>
</tr>
</tbody>
</table>

Table 6: **Testing the Discontinuity.** This table shows the coefficient on $1_{\{maturity_{it} > c\}}$, controlling for the trading volume, duration, maturity, and size for each bond, and the recent default rate in each NAIC category. The first row shows the OLS estimate with robust standard errors, while the other rows show the estimates from various RDD methods discussed in Calonico, Cattaneo and Titiunik (2014).

I then examine the effect of life insurance ownership on the response of a bond’s credit spread to the long-term interest rate. Specifically, I follow a fuzzy RDD approach by instrumenting the life insurer share $\phi_{t}^{\text{ins}}$ with the dummy variable $1_{\{maturity_{it} \geq c\}}$ in regression (7) for observations near the threshold (e.g., Lee and Lemieux, 2010). Instead of using interactive fixed effects, the identification relies on the discontinuity of the investor base around the threshold. In other words, I am now comparing the co-movement seen in bonds slightly above the threshold to those seen in bonds slightly below the threshold. Specifically, I run the following two-stage regression

\[
\begin{align*}
\phi_{t}^{\text{ins}} &= \alpha + \beta \cdot 1_{\{maturity_{it} > c\}} + \Gamma X_{it} + \epsilon_{it} \\
y_{it} &= \left( \beta_{2} \cdot 1_{\{\text{NAIC 2}\}} + \beta_{3} \cdot 6 \cdot 1_{\{\text{NAIC 3--6}\}} \right) y_{it}^{(10)} + \\
&\quad \left( \gamma_{2} \cdot 1_{\{\text{NAIC 2}\}} + \gamma_{3} \cdot 6 \cdot 1_{\{\text{NAIC 3--6}\}} \right) \phi_{t}^{\text{ins}} y_{it}^{(10)} + \alpha_{t} + \Gamma X_{it} + \epsilon_{it}.
\end{align*}
\]

The first stage estimates the effect of the maturity cutoff on the life insurer share $\phi_{t}^{\text{ins}}$. The second stage estimates the effect of the life insurer share $\phi_{t}^{\text{ins}}$ on the comovement between the long-term interest rate and credit spreads, using $1_{\{maturity_{it} > c\}}$ as an instrumental variable.\(^{10}\) I choose a small bandwidth of 1 year on both sides of the threshold.

\(^{9}\)There are limited variations remaining if I focus on the much smaller sample around the threshold while still imposing the fixed effects.

\(^{10}\)I instrument $1_{\{\text{NAIC } k\}} \cdot \phi_{t}^{\text{ins}} y_{it}^{(10)}$ with $1_{\{\text{NAIC } k\}} \cdot 1_{\{maturity_{it} > c\}} y_{it}^{(10)}$.  

29
to isolate the impacts of the discontinuity.\textsuperscript{11}

Table 7 presents the estimates from the RDD regressions above. First, the first-stage $F$-stats both before and after the Financial Crisis are well above the conventional threshold for weak instruments in Stock and Yogo (2005), again confirming the validity of the discontinuity. Second, after the Financial Crisis, we obtained negative and significant coefficients on $\varphi_{it}^{\text{Ins}} y_{t}^{(10)}$. The results show that life insurer holdings amplify the negative comovement between the long-term interest rate and credit spreads. It is worth noting that the special role of life insurers began after the Financial Crisis, as the coefficients on $\varphi_{it}^{\text{Ins}} y_{t}^{(10)}$ were either insignificant (NAIC 2) or significantly positive (NAIC 3-6) before the Financial Crisis.

<table>
<thead>
<tr>
<th></th>
<th>2000-2006</th>
<th>2010-2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_2$</td>
<td>0.320</td>
<td>-0.528***</td>
</tr>
<tr>
<td></td>
<td>[1.504]</td>
<td>[-4.148]</td>
</tr>
<tr>
<td>$\gamma_{3-6}$</td>
<td>1.444***</td>
<td>-1.173***</td>
</tr>
<tr>
<td></td>
<td>[2.708]</td>
<td>[-4.317]</td>
</tr>
<tr>
<td>Time FE</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RDD</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.733</td>
<td>.644</td>
</tr>
<tr>
<td>First-stage $F$</td>
<td>32.7</td>
<td>7253.7</td>
</tr>
<tr>
<td>Identifying Bonds</td>
<td>562</td>
<td>1482</td>
</tr>
</tbody>
</table>

Table 7: RDD Regressions. This table shows the coefficients estimated from regression (8), with the instrument, instead of interactive fixed effects, controlling for the trading volume, duration, maturity, size, coupon amount, and coupon frequency for each bond, and the recent default rate for each NAIC category. The first column shows the result for the pre-Crisis sample, while the second column shows the result for the post-Crisis sample. The statistical significance is based on standard errors clustered at the NAIC category and year-month levels, *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

4.4 Bond Transactions

So far, I have shown that declines in the long-term interest rate have a larger impact on bonds held by life insurers after the Financial Crisis. The main hypothesis is that

\textsuperscript{11}Table A.1 in the Appendix offers additional robustness checks with alternative bandwidth choices.
life insurers’ risk-bearing capacity becomes more restricted when a lower long-term interest rate erodes their equity (see Section 4.1). To further verify the mechanism, I examine the bond transaction pattern of life insurers following movements in the long-term interest rate. Specifically, I expect life insurers to rebalance their bond portfolio towards safer bonds after the long-term interest rate falls.

I use the following empirical specification to test the hypothesis that life insurers rebalance towards safer bonds after declines in the long-term interest rate,

\[
\frac{\text{Net Purchase}^{(m)}_{k,t}}{\text{Market Equity}_t} = \alpha_t + \alpha_k + \sum_{k=2}^{6} \beta_k \cdot 1\{\text{NAIC } k\} \cdot \Delta y^{(10)}_t + \Gamma X_{kt} + \epsilon_{kt}. 
\]  

(9)

Here Net Purchase\textsuperscript{(m)}\textsubscript{k,t} is all life insurers’ net purchases\textsuperscript{12} of NAIC k bonds in a m-month period after month t. The outcome variable is normalized by the aggregate month-end market equity of all US life insurers. On the right-hand side, \( \Delta y^{(10)}_t \) is the change in the 10-year Treasury yield during month t. After controlling for year-month fixed effects, the coefficients \( \beta_k \) measure the purchases of NAIC k bonds relative to NAIC 1 bonds, following a 1% increase in the 10-year Treasury yield. I also include NAIC fixed effects to control market size differences across credit ratings.

Table 8 shows the estimated coefficients from regression (9) for the post-Crisis period. After an increase in the 10-year Treasury yield, life insurers purchase more bonds from NAIC 2-5 relative to NAIC 1, tilting their bond portfolio towards riskier segments of the corporate bond market. The effects are large and significant except for NAIC 6.\textsuperscript{13} After a 1% increase in the 10-year Treasury yield, life insurers purchase more lower-rating bonds than NAIC 1 bonds in the following 6 months, and the difference amounts to more than 0.7% of their market equity for bonds in NAIC 2 and more than 2% for bonds in NAIC 3, 4, and 5.

\textsuperscript{12}Net purchases are defined as the total new purchases subtracting the total disposals including bonds sold and matured.

\textsuperscript{13}NAIC 6 (bonds rated CC and lower) is the smallest segment of the corporate bond market where trading is relatively infrequent. Life insurers also own relatively fewer NAIC 6 bonds.
<table>
<thead>
<tr>
<th></th>
<th>1 month</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_2$</td>
<td>0.331***</td>
<td>0.723***</td>
</tr>
<tr>
<td></td>
<td>[526.5]</td>
<td>[36.11]</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>0.423***</td>
<td>2.256***</td>
</tr>
<tr>
<td></td>
<td>[20.17]</td>
<td>[14.92]</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>0.522***</td>
<td>2.297***</td>
</tr>
<tr>
<td></td>
<td>[25.04]</td>
<td>[14.63]</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>0.553***</td>
<td>2.433***</td>
</tr>
<tr>
<td></td>
<td>[21.34]</td>
<td>[13.13]</td>
</tr>
<tr>
<td>$\beta_6$</td>
<td>0.224</td>
<td>0.327</td>
</tr>
<tr>
<td></td>
<td>[1.323]</td>
<td>[0.288]</td>
</tr>
</tbody>
</table>

NAIC FE ✓ ✓
Time FE ✓ ✓
$R^2$ .851 .908

Table 8: **Insurer Bond Transactions.** This table shows the coefficients estimated from regression (9), controlling for the recent default rate for each NAIC category. The first column shows the result for 1-month purchases, while the second column shows the result for 6-month purchases. The statistical significance is based on standard errors clustered at the NAIC category level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5 An Intermediary Asset Pricing Model

In this section, I build an intermediary asset pricing model to explain the empirical findings. As in He and Krishnamurthy (2013), the risk-bearing capacity of intermediaries (life insurers) is key to credit spreads. As in Koijen and Yogo (2023), life insurers take on leverage by borrowing from households and investing in corporate bonds. Importantly, life insurers face duration mismatch as in Section 4.1, and their equity decreases with the long-term interest rate. The equity drawdown increases life insurers’ effective risk aversion, which leads to higher credit spreads in equilibrium.

5.1 Model Setup

**Investors.** There are three groups of investors in the model — life insurers, preferred-habitat investors, and households.
Life insurers invest in corporate bonds and Treasuries while issuing long-term annuities to households. The duration mismatch between insurers' assets (corporate bonds and Treasuries) and liabilities (annuities) exposes them to interest rate risk. When the long-term interest rate falls, insurers' liabilities increase more than their assets, and they incur equity losses.

Preferred-habitat investors include all other investors of corporate bonds (e.g., mutual funds and pension funds). For simplicity, their demand for corporate bonds is assumed to be reduced-form functions of bond prices.

Households invest in long-term annuities and Treasuries. Importantly, households do not directly invest in corporate bonds but instead through life insurers. This assumption is consistent with existing studies such as Koijen and Yogo (2023) and Bretschger et al. (2022), which show that institutional investors capture most of the corporate bond market. Retail investors only own a small fraction of corporate bonds.

The investors’ balance sheets are as follows.

<table>
<thead>
<tr>
<th>Life Insurers</th>
<th>Preferred-habitat Investors</th>
<th>Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assets</td>
<td>Liabilities</td>
<td>Assets</td>
</tr>
<tr>
<td>Corp. Bonds</td>
<td>Annuities</td>
<td>Corp. Bonds</td>
</tr>
<tr>
<td>Treasuries</td>
<td>Net Worth</td>
<td>Net Worth</td>
</tr>
</tbody>
</table>

**Treasuries and Annuities.** Time is continuous. Treasuries are long-term consol bonds with a geometric maturity structure. The Treasuries have a price $P^T_i$, coupon rate $\phi^T$, and a geometric decaying rate $\lambda^T$. Specifically, each bond pays a stream of coupon payments $\phi^T dt$ and has a face value that decays over time at a constant rate of $\lambda^T$. The return rate on Treasuries is

$$dr^T_i = \left(\frac{\phi^T - \lambda^T P^T_i}{P^T_i}\right)dt + \frac{dP^T_i}{P^T_i},$$

where $\phi^T dt$ captures the coupon payments, $\lambda^T P^T_i dt$ captures the depreciated face value, and $dP^T_i$ is the capital gain from price fluctuations. Based on the geometric decaying maturity structure, the average maturity of this bond is $\tau^T = 1/\lambda^T$.

Annuities are similar consol bonds with a price $P^L_i$, coupon rate $\phi^L$, and a geometric
decaying rate $\lambda^L$. Annuities have a maturity of $\tau^L = 1/\lambda^L$ and a return rate of

$$dr_t^L = \frac{(\phi^L - \lambda^L P_t^L) dt}{p_t^L} + \frac{dP_t^L}{P_t^L}.$$

We denote the yield of Treasuries as the expected return rate $\mu_t^T = \mathbb{E}_t[dr_t^T]/dt$ and the yield of annuities as $\mu_t^L = \mathbb{E}_t[dr_t^L]/dt$.

**Households and the Price of Annuities.** Suppose that the government controls the Treasury yield $\mu_t^T$. In this model, the households determine the term structure (i.e., the pricing of annuities relative to the Treasuries). Since the term structure is not the focus of this paper, I deliberately keep it simple by assuming households are risk-neutral. Therefore, the yields of Treasuries and annuities are equalized in equilibrium,

$$\mu_t^T = \mu_t^L.$$

I further consider an equilibrium with a constant Treasury yield and prices (i.e., $dP_t^T = dP_t^L = 0$). In this case, the prices of Treasuries and annuities are given by the following Gordon growth formulas,

$$P_t^T = \frac{\phi^T}{\mu_t^T + (1/\tau^T)}, \quad P_t^L = \frac{\phi^L}{\mu_t^L + (1/\tau^L)}.$$ (10)

Corresponding to the standard Gordon formula,$^{14}$ the current dividend rate of the Treasuries is $\phi^T$, the required return rate is $\mu_t^T$, and the dividend growth rate is minus the depreciation rate $-\lambda^T = -1/\tau^T$.

When the government (unexpectedly) cuts the Treasury yield $\mu_t^T$, it reduces the annuity yield $\mu_t^L$ of the same magnitude. According to (10), the reduction in $\mu_t^L$ increases the price of annuities $P_t^L$, making life insurers’ liabilities more expensive. The results are very intuitive — for the same stream of coupon payments, the price of the annuities must increase to be consistent with a lower equilibrium yield.

---

$^{14}$The Gordon growth formula gives the price of an asset whose dividend growth rate and required return rate are constant

$$\text{Price} = \frac{\text{Dividend Rate}}{\text{Required Return Rate} - \text{Dividend Growth Rate}}.$$
Corporate Bonds. There exists $N$ corporate bonds. For tractability, I assume that corporate bonds are short-term. The return rate on bond $n \in \{1, \ldots, N\}$ is
\[
d r^n_t = \frac{\phi^n}{P^n_t} \, dt - d j^n_t,
\]
where $\phi^n \, dt$ is bond $n$’s coupon rate and $d j^n_t$ is a compensated Poisson jump process with intensity $\nu^n$ that captures the bond’s credit risk. In a default event, the process $d j^n_t$ generates a jump of size one, meaning that the entire value of the bond is lost. The corporate bond yields are defined as $\mu^n_r, n_t = \mathbb{E}_t [d r^n_t] / dt = \phi^n / P^n_t$.

Life Insurer. There is one representative life insurer that holds corporate bonds and Treasuries while issuing annuities to households. The quantity of annuities is assumed to be exogenous at $L$, and the insurer chooses its holdings of corporate bonds and Treasuries. The insurer has a mean-variance preference over the return on its wealth. The portfolio problem can be written as
\[
\begin{align*}
\max_{\{w^{I,n}_t\}_{n=0}^N} & \quad w^{I,0}_t \mu^I_t + \sum_{n=1}^N w^{I,n}_t \mu^{r,n}_t - \frac{a}{2} \sum_{n=1}^N (w^{I,n}_t)^2 \nu^n_t - \frac{1}{2} \sum_{n=1}^N (w^{I,n}_t)^2 \zeta^n_t, \\
\text{s.t.} & \quad \sum_{n=0}^N w^{I,n}_t - \frac{P^L_t L^L_t}{A^I_t} = 1.
\end{align*}
\]

The insurer has a net worth of $A^I_t$. Its portfolio weight in Treasuries is denoted as $w^{I,0}_t$ while the weight in bond $n$ is $w^{I,n}_t$. In the objective function (11), the insurer maximizes its expected portfolio return minus penalties for the credit risk in the bond portfolio and additional regulatory costs. The parameter $a$ symbolizes the degree of risk aversion, $\nu^n$ is the volatility of process $d j^n_t$ and measures the default risk in bond $n$, and the amount of risk is quadratic in the bond holdings $(w^{I,n}_t)^2$. The insurer incurs additional regulatory cost $\zeta^n$ for holding corporate bonds, potentially including the costs of complying with risk-weighted leverage constraints and passing stress tests. Following Koijen

---

15 In practice, the quantity of life insurers’ liabilities is stable as they are typically long-term products with few early withdrawals (e.g., Chodorow-Reich, Ghent and Haddad, 2021).

16 Appendix B.1 presents a foundation for the objective function in a dynamic setting.

17 Life insurers also face other potential costs such as transaction and informational costs, which are conceptually similar to the regulatory cost from the modeling perspective.
and Yogo (2023), the regulatory cost is assumed to be quadratic in the holdings. In the balance sheet constraint (12), $L$ is the exogenous quantity of annuities, and $-P^L_t L/A^L_t$ is the portfolio weight in annuity liabilities. The constraint holds when the total portfolio weights in Treasuries, bonds, and annuities sum to one. We can further combine the risk aversion term and the regulatory cost term as

$$
\frac{a}{2} \sum_{n=1}^{N} (w^I_{t,n})^2 \nu^n + \frac{1}{2} \sum_{n=1}^{N} (w^I_{t,n})^2 \zeta^n = \frac{1}{2} \sum_{n=1}^{N} (a \nu^n + \zeta^n)(w^I_{t,n})^2 := \frac{1}{2} \gamma^n \sum_{n=1}^{N} (w^I_{t,n})^2,
$$

where $\gamma^n := a \nu^n + \zeta^n > 0$ measures the total cost of holding bond $n$ for the insurer.

**Preferred-Habitat Investors.** The preferred-habitat investors also participate in the corporate bond market. I denote the shares of bond $n$ held by the preferred-habitat investors as $D^P_{t,n}$. I assume that the preferred-habitat investors have the following demand functions

$$
\log D^P_{t,n} = \alpha^n - \beta \log P^t_n.
$$

In this specification, $\beta$ is the price elasticity of demand, and the intercept $\alpha^n$ captures the average propensity to hold bond $n$ by the preferred-habitat investors.

**Asset supply and Market Clearing.** The Treasuries are supplied perfectly elastically to clear the market at the exogenously chosen yield.

The supplies of corporate bonds are constant at $B^B_{t,n} \equiv B^n$. The market for bond $n$ clears when

$$
 \frac{w^I_{t,n} A^L_t}{P^t_n D^P_{t,n}} = P^B_{t,n} B^n.
$$

Market clearing requires that the demand from the life insurer $w^I_{t,n} A^L_t$ and the demand from preferred-habitat investors $P^B_{t,n} D^P_{t,n}$ add to the total market cap $P^B_{t,n} B^n$.

---

18In Section Section 3.3, I documented the effects of the long-term interest rate on corporate bond issuance. It is worth noting that these effects are small compared to the overall size of the bond market and realize gradually. Hence, they are unlikely to change in the main conclusions in this Section.
Equilibrium. Given the life insurers’ net worth and holding costs \(\{A^n, \gamma^n\}\), the habitat demand \(\{\alpha^n, \beta^n\}\), asset supplies \(\{L, B^n\}\), and asset characteristics \(\{\phi^n, \phi^T, \phi^L, \tau^L, \tau^T\}\), an equilibrium is a mapping from the Treasury yield \(\mu^T_t\) to insurer portfolio weights \(\{w^n_I, \gamma^n\}\), asset supplies \(\{L, B^n\}\), and asset characteristics \(\{\phi^n, \phi^T, \phi^L, \tau^L, \tau^T\}\), and asset prices \(\{P^L, P^n\}\) that satisfy the insurer’s portfolio choice problem (11)-(12), the habitat demand function (13), and the market clearing conditions (14).

5.2 Analytical Insights

Next, I consider a scenario where the government unexpectedly reduces the Treasury yield from \(\mu\) to \(\mu^T < \mu\), focusing on how the Treasury yield shock affects the life insurer’s net worth and bond prices.

When the Treasury yield drops, long-term assets, such as the Treasuries and annuities, are repriced according to the Gordon formula (10). As a result, the life insurer’s net worth could also change. Denote the insurers’ net worth before and after the shock as \(A\) and \(A^\prime\), respectively. The change in net worth follows

\[
\hat{A} - A = T \left( \frac{P^T - \hat{P}^T}{\mu + (1/\tau^T)} - \frac{P^L - \hat{P}^L}{\mu + (1/\tau^L)} \right)
\]

Here \(T = Aw^{I,0}/P^T\) is the quantity of Treasuries the insurer held before the shock. A lower Treasury yield raises the values of Treasuries and annuities (\(\hat{P}^T > P^T, \hat{P}^L > P^L\)). The change in the insurer’s net worth of the insurer, \(\hat{A} - A\), is determined by the extent to which Treasuries and annuities are repriced. Consider a simple case where the Treasury and the annuity have the same coupon rate \((\phi^T = \phi^L = \phi)\), where

\[
\hat{A} - A = \phi (\mu - \hat{\mu}) \left[ T \frac{1}{(\mu + (1/\tau^T))(\mu + (1/\tau^T))} - L \frac{1}{(\mu + (1/\tau^L))(\mu + (1/\tau^L))} \right].
\]

If annuities have a longer maturity than Treasuries \((\tau^L > \tau^T)\) and the insurer issues more annuities than the Treasuries it holds \((L > T)\), then the insurer’s net worth declines with the Treasury yield (i.e., \(\hat{A} < A\)), which corresponds to the situation after the Financial Crisis (Section 4.1).
To understand how the insurer’s net worth affects bond credit spreads, it is useful to characterize the solution to the portfolio problem (11)-(12). The first-order condition for bond \( n \) is

\[
\underbrace{\mu^r_{t,n} - \mu^T_t}_{\text{credit spread}} = \underbrace{aw^I_t v^n}_{\text{risk premium}} + \underbrace{\zeta^n w^n_{t,n}}_{\text{regulation premium}} = \gamma^n w^n_{t,n}. \tag{16}
\]

We can write equation (16) as

\[
w^n_{t,n} = \frac{\mu^r_{t,n} - \mu^T_t}{\gamma^n}, \tag{17}
\]

which is the standard portfolio choice condition under mean-variance preferences. \( w^n_{t,n} \), the insurer’s portfolio weight in bond \( n \), equals the risk premium \( \mu^r_{t,n} - \mu^T_t \) divided by the cost parameter \( \gamma^n \).\(^{19}\)

Equation (17) allows us to express \( A^I_t w^n_{t,n} \), the (dollar) amount of corporate bond \( n \) demanded by the life insurer, as

\[
A^I_t w^n_{t,n} = \frac{\mu^r_{t,n} - \mu^T_t}{\gamma^n / A^I_t}.
\]

The demand is given by the credit spread divided by the insurer’s effective risk aversion, which I define as \( \gamma^n / A^I_t \), the total holding cost \( \gamma^n \) divided by net worth \( A^I_t \). Under duration mismatch, a lower Treasury yield squeezes the insurer’s net worth, elevating the insurer’s effective risk aversion. As a result, the insurer’s demand for risky bonds decreases, putting upward pressure on equilibrium credit spreads.

I make two further assumptions before presenting the analytical results. The first assumption states that the life insurer is subject to a duration mismatch of the same kind found in Section 4.1. In Appendix B.2, I provide a sufficient condition for this assumption to hold in equilibrium. The second assumption is that the preferred-habitat demand is downward-sloping. The assumption is standard in the literature of institutional bond demand and supported by various empirical estimates (Bretscher et al., 2022; Darmouni, Siani and Xiao, 2022).

\(^{19}\)In the absence of the regulatory cost \( \zeta^n \), the parameter \( \gamma^n = av^n\) equals the risk aversion coefficient \( a \) times the default risk \( v^n \), which is exactly the solution of a standard mean-variance portfolio problem.
Assumption 1 The life insurer is subject to duration mismatch (i.e., $\frac{\partial \hat{A}}{\partial \mu} > 0$ for $\mu \in [0, \mu]$).

Assumption 2 The preferred-habitat demand functions are downward-sloping (i.e., $\beta \leq 0$).

The next Proposition summarizes the main analytical results from this model.\textsuperscript{20}

**Proposition 1** Under assumptions 1 and 2, the following predictions hold when the Treasury yield $\mu_t^T$ decreases from $\mu$ to $\mu < \mu$:

1. the insurer’s wealth decreases
2. the insurer’s exposure to credit risk $w_i^{1,n}$ increases for all $n > 0$
3. the credit spread $\mu_i^n - \mu_t^T$ increases for all $n > 0$

In addition, the magnitudes of predictions 2-3 increase in the duration mismatch (i.e., $\frac{\partial \hat{A}}{\partial \mu}$).

Proposition 1 shows that when the yield on long-term Treasuries falls, the insurer’s net worth shrinks as it faces duration mismatch. The insurer’s portfolio becomes more tilted towards risky bonds, and the insurer is more exposed to the risk and regulatory burdens of corporate bonds. As a result, the equilibrium credit spreads increase. Moreover, the impact of a Treasury yield shock is larger when the life insurer’s duration mismatch is more severe (i.e. when its net worth is more sensitive to the shock).

### 5.3 Quantitative Analysis

In this Section, I match the model to empirical estimates and key moments in data in order to quantify the contribution of life insurers’ duration mismatch to the comovement between the long-term interest rate and corporate bond credit spreads.

Table 9 discusses model calibration. I study 5 types of corporate bonds ($N = 5$). They correspond to bonds in NAIC 1, NAIC 2, NAIC 3, NAIC 4, and NAIC 5-6, respectively. I combine NAIC 5 and 6 into one category because NAIC 6 on its own is a small category with fewer bonds and life insurance holdings and is difficult to calibrate accurately. I normalize all the coupon rates and bond supplies as $1$ ($\phi^T = \phi^L = \phi^n = $).\textsuperscript{20}

I lay out the proof in Appendix B.3.
B^n = 1). I let habitat investors’ demand elasticity be $\beta = 1.106$, which is the demand elasticity of mutual funds estimated by Darmouni, Siani and Xiao (2022). I vary the values of the intercepts $\{\alpha^n\}$ to match the market share of life insurers in each category at the end of 2010.\footnote{In Section 4.2, I show that the comovement of interest only exists in bonds held by life insurers. Therefore, I calibrate $\alpha^n$ to those bonds with life insurance ownership (see column 2 of Table A.2).} I choose an initial insurer net worth of $A = 10$ to target a market leverage ratio of roughly 25% (Figure 5). I set $\tau^T = 10$ and $\tau^L = 20$, so the maturity of Treasuries is 10 years, and the maturity of annuities is 20 years. I calibrate the annuities supply $L = 0.2$ to match the empirically estimated duration mismatch (Section 4.1). I choose $\gamma^1$, the holding cost parameter for NAIC 1, by targeting an (NAIC 1)-Treasury spread of 1.5%, which is roughly consistent with the observed Aaa-Treasury spread in 2010. Finally, I calibrate the holding cost parameters $\{\gamma^n\}$ for $n \geq 2$ to match the relative portfolio holdings of life insurers at the end of 2010. We can infer that the holding cost of NAIC $k$ is high if life insurers hold relatively few NAIC $k$ bonds.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|}
\hline
Parameter & Target \\
\hline
$N = 5$ & NAIC 1, NAIC 2, NAIC 3, NAIC 4, NAIC 5-6 \\
$\phi^T = \phi^L = \phi^n = B^n = 1$ & Normalization \\
$\beta = 1.106$ & Demand Elasticity (Darmouni et al., 2022) \\
$\{\alpha^1, \ldots, \alpha^N\}$ & Life insurers’ share in each category \\
$A = 10$ & Leverage Ratio $\approx$ 25% \\
$\tau^T = 10$ & Treasury Maturity = 10 yrs \\
$\tau^L = 20$ & Annuity Maturity = 20 yrs \\
$L = 0.2$ & Estimated Duration Mismatch $\partial \hat{A}/\partial \hat{\mu} = 5.32$ \\
$\gamma^1 = 0.02$ & (NAIC 1)-Treasury Spread $(\mu_t^{1} - \mu_t^{T} = 1.5\%)$ \\
$\gamma^2 = 0.0458$ & Relative portfolio weight $w_t^{1,2}/w_t^{1,1} = 0.877$ \\
$\gamma^3 = 4.02$ & Relative portfolio weight $w_t^{1,3}/w_t^{1,1} = 0.0764$ \\
$\gamma^4 = 10.8$ & Relative portfolio weight $w_t^{1,4}/w_t^{1,1} = 0.0286$ \\
$\gamma^5 = 250$ & Relative portfolio weight $w_t^{1,5}/w_t^{1,1} = 0.005$ \\
\hline
\end{tabular}
\caption{Model Calibration. This table summarizes the values of key model parameters and their empirical counterparts.}
\end{table}
I next consider an unexpected shock that moves the 10-year Treasury yield from $\mu = 2.5\%$ to $\hat{\mu} = 3.5\%$. Table 10 compares the changes in credit spreads of NAIC $k$ ($k \geq 2$) relative to NAIC 1 (i.e., $\Delta(\mu_r^{n, t} - \mu_r^{r, 1})$) generated by the model with those from empirical estimates (Figure 2). The model is able to generate large and negative responses in credit spreads following increases in the long-term Treasury yield. As shown in Table 10, the duration mismatch channel can explain almost the entirety of the credit spread responses in NAIC 2 and NAIC 3 and around 60% of the credit spread response in NAIC 4. The quantitative results suggest that life insurers’ duration mismatch is the key driver of the comovement between the long-term interest rate and credit spreads in most corporate bonds, as bonds in NAIC 1-4 account for almost 90% of the entire corporate bond market.

<table>
<thead>
<tr>
<th>$\Delta(\mu_r^{n, t} - \mu_r^{r, 1})$</th>
<th>NAIC 2</th>
<th>NAIC 3</th>
<th>NAIC 4</th>
<th>NAIC 5-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model (%)</td>
<td>-0.08</td>
<td>-0.468</td>
<td>-0.449</td>
<td>-0.580</td>
</tr>
<tr>
<td>Data (%)</td>
<td>-0.08</td>
<td>-0.48</td>
<td>-0.75</td>
<td>-4.2</td>
</tr>
<tr>
<td>Fraction Explained</td>
<td>100.00</td>
<td>97.51%</td>
<td>59.92%</td>
<td>13.82%</td>
</tr>
</tbody>
</table>

Table 10: Model Performance. This table summarizes the change in credit spreads $\Delta(\mu_r^{n, t} - \mu_r^{r, 1})$ produced by the model and the data following a 1% increase in the 10-year Treasury yield.

The model has several new implications for unconventional monetary policy. In recent years, the Federal Reserve has adopted policies aiming to control long-term interest rates (e.g., QE and QT). For example, some believe that QE and central bank asset purchases are effective at lowering the long-term interest rate (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; D’Amico and King, 2013; Vayanos and Vila, 2021), which potentially boosts economic activities. However, my results show that the effects of QE are achieved at the cost of increased corporate bond credit spreads, which could offset some of the postulated economic benefits of QE. Since 2022, the Federal Reserve has conducted QT to control inflation, which could lower the long-term interest rate and have unintended expansionary effects through the corporate bond market.

22 The empirical response for NAIC 5-6 is the average of the responses in NAIC 5 and NAIC 6 weighted by their respective outstanding amounts in 2010.
Meanwhile, life insurers have smaller direct price impacts in NAIC 5 and 6, as the model explains only 13.82% of the credit spread response in that category. This finding is not surprising because life insurers have a strong aversion towards NAIC 5 and 6 bonds and hold few of them (see, e.g., Table A.2). In practice, bonds in NAIC 5 and 6 are mostly owned by mutual funds. It is possible that the credit spread responses generated by life insurers have spillover effects on the balance sheets of other investors like mutual funds, which further amplifies the initial credit spreads responses (e.g., Darmouni, Siani and Xiao, 2022). Future research could explore the potential interaction between life insurers and other investors, which is beyond the scope of this paper. Other mechanisms discussed in Section 3.5, including the risk exposure of pension funds and the information channel, could have also contributed to the comovement in NAIC 5 and 6.

6 Conclusions

In this paper, I document a shift in the comovement between the long-term interest rate and corporate bond credit spreads. In particular, declines in the long-term interest rate led to large increases in credit spreads after the Financial Crisis, which is important given the long-run trend of the falling long-term interest rate and policies that specifically target the long-term interest rate (QE and QT). I further establish that the new comovement is linked to life insurers’ duration mismatch and bond holding. Life insurers are the largest institutional investor group in the corporate bond market. After the Financial Crisis, they face a large duration mismatch, and their equity value declines sharply with the long-term interest rate. I present causal evidence that the comovement is more pronounced in bonds held by life insurers. I build an intermediary asset pricing model with life insurers to account for the empirical findings. In the model, declines in the long-term interest rate squeeze life insurers’ equity and increase their effective risk aversion, resulting in higher equilibrium credit spreads. I show that the model can explain a large fraction of the observed comovement between the long-term interest rate and corporate bond credit spreads.
References


46


### A Supplementary Results

Figure A.1: **The 10-year Treasury Yield and Bond Credit Spreads (2010-2019).** The figure plots the 10-year Treasury yield and the spreads of corporate bond indices relative to the index of AAA bonds. The 10-year Treasury yield is shown as the solid blue line and corresponds to the y-axis on the right-hand side. The credit spreads are shown as dashed red lines and correspond to the y-axis on the left-hand side.
Figure A.2: The 10-year Treasury Yield and Bond Credit Spreads (2001-2007). The figure plots the 10-year Treasury yield and the spreads of corporate bond indices relative to the index of AAA bonds. The 10-year Treasury yield is shown as the solid blue line and corresponds to the y-axis on the right-hand side. The credit spreads are shown as dashed red lines and correspond to the y-axis on the left-hand side.
Figure A.3: **Impulse Responses of Spreads Relative to Treasuries (2010-2019).** The figure plots the cumulative responses of credit spreads relative to Treasury securities to a 1% increase in the 10-year Treasury yield and 95% confidence intervals based on Newey-West standard errors. The maximum length of lags is 30 trading days.

Figure A.4: **Impulse Responses of Yield Indices (2010-2019).** The figure plots the cumulative responses of yield indices to a 1% increase in the 10-year Treasury yield and 95% confidence intervals based on Newey-West standard errors. The maximum length of lags is 30 trading days.
Figure A.5: **Life Insurers’ Share in the Corporate Market.** The figure plots the fraction of US corporate bonds owned by life insurance companies over time. The data is obtained from the Financial Accounts of the United States.

Figure A.6: **Life Insurers’ Interest Rate Risk Exposure Over Time.** The figure plots the two-year rolling estimates of $\beta$ from regression (5), controlling for the market return and changes in the one-month Treasury yield. The blue segment indicates the pre-Crisis sample, and the red segment indicates the post-Crisis sample. The stock returns are winsorized at 2.5% and 97.5% thresholds. The shaded area indicates 95% confidence intervals using robust standard errors.
## Robustness: Bandwidth Choice

This figure plots the coefficients estimated from regression (8) in the post-Crisis sample for different choices of bandwidth. The controls are the same as in Table 7. The statistical significance is based on standard errors clustered at the NAIC category and year-month levels, \(^* p < 0.10\), \(^{**} p < 0.05\), \(^{***} p < 0.01\).

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>1yr</th>
<th>2yrs</th>
<th>4yrs</th>
<th>6yrs</th>
<th>8yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\gamma_2)</td>
<td>-0.455***</td>
<td>-0.528***</td>
<td>-0.399***</td>
<td>-0.339***</td>
<td>-0.304***</td>
</tr>
<tr>
<td>(\gamma_{3-6})</td>
<td>-1.085**</td>
<td>-1.173***</td>
<td>-1.189***</td>
<td>-1.231***</td>
<td>-1.485***</td>
</tr>
<tr>
<td>Time FE</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(R^2)</td>
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<td>.644</td>
<td>.664</td>
<td>.663</td>
<td>.629</td>
</tr>
<tr>
<td>First-stage (F)</td>
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<td>7253.7</td>
<td>6821.2</td>
<td>426.5</td>
<td>578.4</td>
</tr>
<tr>
<td>Identifying Bonds</td>
<td>797</td>
<td>1482</td>
<td>1889</td>
<td>2228</td>
<td>2676</td>
</tr>
</tbody>
</table>

### Life Insurance Ownership (end of 2010)

This figure summarizes life insurers’ bond ownership at the end of 2010. The first column shows the fraction of bonds with positive insurer holdings. The second column shows the average life insurance ownership share in bonds with life insurance ownership. The third column shows the maximum life insurer share for each category. The last column shows the standard deviation of life insurer shares in bonds with life insurance ownership.

| NAIC | \(\mathbb{1}\{\varphi_{it}^{\text{Ins}} > 0\}\) | \(\mathbb{E}[\varphi_{it}^{\text{Ins}} | \varphi_{it}^{\text{Ins}} > 0]\) | \(\max \varphi_{it}^{\text{Ins}}\) | std\((\varphi_{it}^{\text{Ins}} | \varphi_{it}^{\text{Ins}} > 0)\) |
|------|-----------------|-----------------|-----------------|-----------------|
| NAIC 1 | 84.6% | 32.5% | 100% | 0.228 |
| NAIC 2 | 98.5% | 39.2% | 98.6% | 0.218 |
| NAIC 3 | 94.3% | 16.0% | 95.9% | 0.158 |
| NAIC 4 | 84.6% | 6.0% | 50.1% | 0.075 |
| NAIC 5-6 | 65.2% | 3.9% | 60.4% | 0.065 |
B Model Details

B.1 A Dynamic Portfolio Choice Problem

The insurer’s portfolio optimization problem can be derived from the following dynamic setting. In continuous time, the insurer’s wealth evolution follows

\[
A_t = \left[ (w_t^{0,0} A_t^I)\mu_t^T + \sum_{n=1}^{N} (w_t^{I,n} A_t^I)\mu_t^{r,n} \right] dt - \sum_{n=1}^{N} (w_t^{I,n} A_t^n) dJ_t^n - \left[ \sum_{n=1}^{N} \frac{\nu^n}{2} (w_t^{I,n})^2 \right] A_t^I dt.
\]

The insurer has the following mean-variance preference over its return on assets

\[
E_t \left[ \frac{dA_t^I}{A_t^I} \right] - \frac{a}{2} \text{Var}_t \left[ \frac{dA_t^I}{A_t^I} \right].
\]

The drift and volatility can be derived from the wealth evolution as

\[
E_t \left[ \frac{dA_t^I}{A_t^I} \right] = \left[ w_t^{I,0} \mu_t^T + \sum_{n=1}^{N} w_t^{I,n} \mu_t^{r,n} - \sum_{n=1}^{N} \frac{\nu^n}{2} (w_t^{I,n})^2 \right] dt,
\]

\[
\text{Var}_t \left[ \frac{dA_t^I}{A_t^I} \right] = \left[ \sum_{n=1}^{N} (w_t^{I,n})^2 \nu^n \right] dt,
\]

where the second line uses the fact that the volatility process of a compensated Poisson process coincides with its jump intensity \( \text{Var}_t(dJ_t^n) = \nu^n dt \).

Plugging the expressions for the drift and volatility into the mean-variance utility function, we obtain the objective function in (11).

B.2 A Sufficient Condition for Duration Mismatch

Now we show that a set of sufficient conditions for Assumption 1 is that (1) \( \tau^T < \tau^L \), (2) bond supplies \( B^n \) are sufficiently large, and (3) holding costs \( \gamma^n \) are sufficiently small.

First, differentiating equation (15),

\[
\frac{d\hat{A}}{d\hat{\mu}} = \frac{L\phi^L}{(\hat{\mu} + (1/\tau^L))^2} - \frac{T\phi^T}{(\hat{\mu} + (1/\tau^T))^2}.
\]
A set of sufficient conditions for $\partial \hat{A} / \partial \hat{\mu} > 0, \forall \hat{\mu} \in [0, \infty]$ is that
\[
\tau^T < \tau^L \tag{B.1}
\]
\[
T\phi^T < L\phi^L \tag{B.2}
\]
Condition (B.2) can be written as
\[
\frac{w^{I,0} A}{p^T} \phi^T < L\phi^L
\]
\[
w^{I,0} A(\mu + \lambda^T) < L\phi^L
\]
\[
w^{I,0} < \frac{L\phi^L}{A(\mu + \lambda^T)}
\]
\[
1 + \frac{L\phi^L}{A(\mu + \lambda^L)} - \sum_{n=1}^{N} w^{I,n} < \frac{L\phi^L}{A(\mu + \lambda^T)}
\]
\[
1 + \frac{L\phi^L(\lambda^T - \lambda^L)}{A(\mu + \lambda^T)(\mu + \lambda^L)} < \sum_{n=1}^{N} w^{I,n} \tag{B.3}
\]
Consider the case with $\gamma^n = 0$. Before the yield shock, the first-order condition implies
\[
\frac{\phi^n}{p^n} = \mu \implies p^n = \frac{\phi^n}{\mu}.
\]
Then the market clearing conditions imply
\[
w^{I,n} = \frac{p^n(B^n - D^{P,n}(p^n))}{A} = \frac{\phi^n}{\mu A} \left[ B^n - D^{P,n} \left( \frac{\phi^n}{\mu} \right) \right].
\]
Thus, condition (B.3) holds for $\gamma^n = 0$ if \{\{B^n\}\} are large enough so that
\[
\sum_{n=1}^{N} \phi^n B^n > \mu A + \frac{\mu L\phi^L(\lambda^T - \lambda^L)}{(\mu + \lambda^T)(\mu + \lambda^L)} + \sum_{n=1}^{N} \phi^n D^{P,n} \left( \frac{\phi^n}{\mu} \right). \tag{B.4}
\]
In Section B.3, I will show that the portfolio weight $w^{I,n}$ decreases in $\gamma^n$. Since $w_i^{I,n}$ is a continuous function in $\gamma^n$, there exists some positive constant condition $\bar{\gamma} > 0$ such that (B.3) holds for $\gamma^n \in (0, \bar{\gamma})$. To summarize, we have now found a set of conditions under which $\partial \hat{A} / \partial \hat{\mu} > 0$ holds:
\[
\gamma^n \in (0, \bar{\gamma}), (B.1), \text{ and } (B.4).
\]
B.3 Proof

Proof of Proposition 1. The market clearing condition (14) can be written as

\[ w_i^{l,n} A_i = P_i^n \left( B^n - D^{P,n}(P^n_i) \right) \]

Under Assumption 2, the right-hand side is increasing in \( P^n_i \). The equation implies that \( P^n_i \) is a function of \( w_i^{l,n} \) and \( A_i \). Denote \( P^n_i = P^n(w_i^{l,n}, A_i) \). It is easy to show that

\[ \frac{\partial P^n_i}{\partial w_i^{l,n}} > 0, \quad \frac{\partial P^n_i}{\partial A_i} > 0. \]

Consider the insurer’s first-order condition

\[ \mu_i^{r,n} - \mu_i^T = \gamma^n w_i^{l,n} \] (B.5)

\[ \frac{\phi^n}{P^n(w_i^{l,n}, A_i)} - \mu_i^T = \gamma^n w_i^{l,n}. \] (B.6)

Differentiating (B.6) yields

\[ \frac{\partial w_i^{l,n}}{\partial \mu_i^T} = - \left[ \gamma^n + \frac{\phi^n}{(P^n_i)^2} \frac{\partial P^n_i}{\partial w_i^{l,n}} \right]^{-1} \left[ 1 + \frac{\phi^n}{(P^n_i)^2} \frac{\partial P^n_i}{\partial A_i} \frac{\partial A_i}{\partial \mu_i^T} \right]. \] (B.7)

Under Assumption 1, \( \partial A_i / \partial \mu_i^T > 0 \), so \( \partial w_i^{l,n} / \partial \mu_i^T < 0 \). That is, the portfolio weight \( w_i^{l,n} \) increases when the Treasury yield \( \mu_i^T \) decreases. From (B.5), we see that the credit spreads must also increase. Equation (B.7) also tells us the magnitude of the effect (i.e., \( \left| \frac{\partial w_i^{l,n}}{\partial \mu_i^T} \right| \)) is increasing in the severity of duration mismatch (i.e., \( \left| \frac{\partial A_i}{\partial \mu_i^T} \right| \)).

We can also show that the portfolio weight \( w_i^{l,n} \) decreases in the holding cost \( \gamma^n \) by differentiating (B.6),

\[ \frac{\partial w_i^{l,n}}{\partial \gamma^n} = - \left[ \gamma^n + \frac{\phi^n}{(P^n_i)^2} \frac{\partial P^n_i}{\partial w_i^{l,n}} \right]^{-1} w_i^{l,n} < 0. \]