Utilising Duration to Mitigate Interest Rate Risk in Bond Portfolio Management: A Quantitative Approach

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Abstract. In the current complex and ever-changing financial market environment, investors face the potential impact of interest rate fluctuations on the value of their investment portfolios. The duration of bonds plays a crucial role in measuring the sensitivity of bond prices to changes in interest rates. To effectively manage this risk, this paper aims to explore an additive calculation method based on bond duration to guide investors in bond portfolio allocation, thus mitigating interest rate risk. Firstly, the characteristics of bonds as the preferred investment choice for most investors and the associated interest rate risk are introduced. Secondly, the research objective of utilising the additivity of bond duration to mitigate interest rate risk is proposed. This paper employs four model methods: discounted cash flow method, Macaulay duration, weighted average duration of a portfolio, and utilisation of duration to reduce interest risk. Based on the principle of additivity of bond duration, the optimal bond portfolio proportions are calculated by weighted averaging the durations of various bonds, thus achieving the avoidance of interest rate risk. Finally, through empirical analysis involving the selection of two bonds, the effectiveness and feasibility of this method in practical investment are validated. This study presents a novel approach for portfolio allocation utilising bond duration, which enhances both the returns and stability of investment portfolios.

Keywords: Investment decision making; Bound; Macaulay duration; Interest rate risk

1 Introduction

As widely embraced investment instruments, bonds are favoured by numerous investors for their characteristics as debt contracts that offer regular interest payments and repayment of principal, with future cash flows predetermined. Typically issued by governments, local authorities, or related entities, bonds possess strong liquidity and lower investment risk. Despite the inherent risks associated with bond investments, they are generally perceived as less risky than stocks and other financial derivatives. In real-life scenarios, most investors tend to mitigate risks, particularly those rational investors who prefer conservative investment approaches. Therefore, bonds are highly favoured as a relatively safe and stable financial product for wealth management.

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However, in financial markets, interest rate risk is a crucial consideration for investors. Fluctuations in interest rates may directly impact bond prices, subsequently affecting the value of investment portfolios. Investors tend to purchase bonds to mitigate this risk primarily due to bonds' fixed interest rate characteristics. When market interest rates rise, the value of already issued fixed-rate bonds decreases because newly issued bonds offer higher interest returns. In contrast, existing bonds cannot adjust their rates to match the market. Therefore, by managing the duration of bonds in a bond portfolio, investors can reduce the extent to which their investment portfolios are affected by interest rate fluctuations, thereby more effectively mitigating interest rate risk. [1] Addressing the abovementioned issue, this paper will analyse how to use duration to reduce interest rate risk for fixed-income securities, using two existing bonds as examples. In this study, the author selected Bond A: 20 Tianjin Infrastructure Investment Series 10 and Bond B: 21 Liu'an Bond Series. This research may contribute to investors who want to use duration to help choose fixed-income securities to reduce risk and thus achieve their investment goals. The rest of this paper is structured as follows. Section 2 will introduce the method used in this research, the use of duration will be presented in Section 3, and the conclusion can be found in Section 4. The reference can be found in the fifth section.

2 Methodology

Investors utilise the principle of duration additivity in bond portfolios to mitigate the impact of interest rate risk on liabilities, primarily based on the mathematical properties of bond duration. Bond duration is a key metric for assessing bond prices' sensitivity to changes in interest rates. [2] The concept of duration involves factors such as the cash flows of bonds, the time to maturity of bonds, and the face value of bonds. Bond prices fall when interest rates rise, whereas bonds rise when interest rates decline. The duration calculation allows investors to quantify this sensitivity, and the additive calculation method enables investors to aggregate the durations of different bonds to obtain the overall duration of the entire investment portfolio. By selecting bonds with complementary durations in the bond portfolio, investors can, to some extent, balance the risk of interest rate fluctuations and thus mitigate the impact of interest rate risk on liabilities [3].

In this process, investors employ four primary methods for calculation: the Discounted Cash Flow method, Macaulay Duration, and Weighted Average Duration of a portfolio. The Discounted Cash Flow method utilises present value calculation to determine the present value of bonds. Secondly, the Macaulay Duration method involves a weighted average of the bond's cash flows to calculate its duration. Subsequently, the bond portfolio's duration is computed using the linear properties of bond duration. Finally, the method of utilising bond duration to mitigate interest rate risk ensures the determination of an optimal investment portfolio by aligning the bond portfolio's duration with the liability term. Consequently, in the field of finance, duration aids investors in evaluating the risk characteristics of bond portfolios and formulating corresponding investment strategies, providing crucial guidance for investors.

2.1 Discounted Cash Flow Method

The Discounted Cash Flow method, abbreviated as DCF, undoubtedly stands out as a highly esteemed authoritative approach when discussing investment evaluation methodologies. Grounded in financial theory, the DCF model aims to assess the intrinsic value of assets with precision and academic rigour that is widely recognised. The DCF model operates on the principle that the value of an asset relies on the discounted value of future cash flows [4]. These cash flows are discounted to present value using an appropriate discount rate to reflect the time value of money and risk (the choice of discount rate depends on the characteristics of the asset).

When discussing methods for bond valuation, the discounted cash flow (DCF) model is widely adopted in finance. Its fundamental principle involves discounting the future cash flows of bonds to their present value to determine a fair price. The future cash flows of bonds consist of future interest payments and principal repayment. Each period's interest is the face value of the bond multiplied by its coupon rate, with the principal repaid in the final period. The discount rate (yield to maturity, YTM) can be substituted with the current market interest rate, such as the Loan Prime Rate (LPR). Factors such as the bond's issue date, maturity date, and coupon rate are considered to ensure an accurate estimation of future cash flows. Assuming the future cash flows of the bond for the next 1 to n years are denoted as C1, C2, C3, ..., Cn, with the final repayment of principal as F, and assuming a constant discount rate denoted as Y, the formula for discounting the future cash flows for n years to the present is as Equation (1).

$$PV_n = \frac{C_1}{(1+y)} + \frac{C_2}{(1+y)^2} + \frac{C_3}{(1+y)^3} + \cdots + \frac{C_n}{(1+y)^n} + \frac{F}{(1+y)^n} \tag{1}$$

The formula enables the calculation of the present value (PV) of periodic interest payments and the bond's PV following investor acquisition. [5] Nonetheless, it is imperative to acknowledge that the Discounted Cash Flow (DCF) model may entail subjective elements in forecasting future cash flows and selecting discount rates. Consequently, considering various factors and alignment with empirical circumstances is warranted when employing this model.

2.2 Macaulay Duration

Macaulay duration is the second significant method investors employ in their investment strategies. Introduced by F.R. Macaulay in 1938, bond duration is a financial concept reflecting the sensitivity of bond prices to changes in interest rates. Essentially, it is a measure of time and represents the average waiting time required for investors to recoup both principal and interest. A longer duration implies higher sensitivity of bonds to interest rate changes, consequently elevating the associated risk level. [6] In investment management, utilising bond duration to mitigate interest rate risk is a widely practised theoretical approach. Macaulay duration is computed as the present value-weighted average time required for all bond cash flows. Here, the weight (W) of each cash flow is determined by the ratio of the present value of that cash flow to the bond price (i.e., the sum of the present values of all cash flows). This weight can be understood as the proportion of the present value of each interest payment in the bond's current value [7]. The formula for calculating Macaulay duration is Equation (2).

$$D = \sum t \times \frac{\frac{C_t}{1+y}^{t}}{PV} \tag{2}$$

2.3 Weighted Average Duration of a Portfolio

The computation of the weighted average duration of a portfolio entails the multiplication of the duration of each constituent bond by its corresponding weight within the portfolio, followed by the summation of these resultant products. Such an approach allows investors to alleviate interest rate exposure by tailoring the allocation of bonds within the portfolio according to their respective durations. By harmonising the weighted average duration of the portfolio with the investor's risk appetite and prevailing market anticipations, it becomes feasible to fine-tune the portfolio's responsiveness to fluctuations in interest rates [8]. The formula for this calculation in Equation (3).

$$D_{portfolio} = \sum_{i=1}^{n} w_i \times D_i \tag{3}$$

2.4 Use Duration to Reduce Interest Risk

Interest rate risk is widely defined in the investment domain as the uncertainty of market interest rates leading to potential losses for investors. Although commonly perceived as a risk faced by commercial banks, investors encounter interest rate risk equally. This risk primarily emanates from fluctuations in market interest rates and the mismatch between the maturity of investment instruments and investors' liabilities. In this context, maturity refers to the expiration date of bonds, quantitatively described by investors through duration. When investors purchase bonds, the duration of the acquired bonds remains fixed. However, if the duration of investors' liabilities (T) exceeds that of the bonds, they may encounter interest rate risk. In such cases, leveraging the linear property of Macaulay duration is pivotal: the duration of an asset portfolio equals the weighted average of the durations of its constituents, where weights represent the proportion of the asset in the entire portfolio. Adjusting the composition of bond portfolios, including purchasing two sets, three sets, or even more bonds to subsequently adjust the bond portfolio's duration to match the liability term, effectively mitigating interest rate risk. [9] This is mathematically represented in Equation (4).

$$T = \sum_{i=1}^{n} w_i \times D_i \tag{4}$$

Sample

In this study, investors have selected two types of bonds for analysis: Bond A and Bond B. To gain a deeper understanding of the characteristics of bonds, it is necessary to examine their fundamental elements, including but not limited to bond face value, coupon rate, coupon frequency, bond maturity, bond present value, and issuing entities.

Bond A, formally known as "20 Tianjin Infrastructure Investment Series 10," is a corporate bond issued by Tianjin Urban Infrastructure Construction Investment Group

Co., Ltd. (hereafter referred to as "Tianjin Urban Investment"), with a total value of 1 billion Chinese yuan. The bond was issued on April 17, 2020, with a maturity date of April 17, 2030, making its tenure ten years. It carries a coupon rate of 4.23%, with annual interest payments and a face value of 100 yuan per bond.

Bond B, officially named "21 Liu'an Bond Series", is issued by Anhui Liu'an New City Construction Investment Co., Ltd. The issuance commenced on October 29, 2021, with a scheduled maturity date of October 29, 2028, resulting in a seven-year tenure. The bond offers a coupon rate of 4.77%, entailing an annual interest payment of 4.77 yuan per bond, with a face value of 100 yuan. Interest payments are made annually.

3 Analysis

3.1 Assumptions

It is assumed that Company A holds a liability due on July 18, 2029, amounting to ¥10,000, and is concerned about potential fluctuations in the interest rate affecting this liability. In response to this concern, the company has opted to employ financial instruments to mitigate the risk associated with interest rate fluctuations. Following deliberations within its financial department, the decision was made to utilise bonds to manage interest rate risk, considering them to be cost-effective and less precarious. This case is an illustrative example demonstrating the utilisation of bonds and duration management for interest rate risk reduction.

3.2 Bond Selection

A comprehensive evaluation of the investment value and risk characteristics of bonds prompted the company to consider various factors before proceeding with bond investments, exemplified by Bond A. The choice of Bond A was influenced by the notable advantages associated with its issuer, Tianjin Urban Construction Investment Group. As a directly administered municipality, Tianjin benefits from robust support from local and central governments, providing a stable endorsement for bonds issued under its authority. Given its status as a significant entity in urban infrastructure development, Tianjin Urban Construction Investment Group holds a AAA credit rating, signifying a highly reliable debt repayment capacity. Amidst the prevailing low-interest-rate environment, Bond A offers a comparatively higher face value interest rate, thus presenting investors with a more appealing return on investment.

Furthermore, Bond A boasts higher liquidity. Considering these factors, the company deems Bond A a reasonable investment choice. The rationale behind opting for Bond B lies in its superior credit rating. According to comprehensive credit assessments, Bond B holds a credit rating of AA with a stable outlook, surpassing the current bond's rating, which stands at AAA. This signifies that Bond B carries relatively lower credit risk, higher safety, and correspondingly attractive interest rates. From the issuer's perspective, the primary operations of the company issuing Bond B exhibit evident regional monopolies and enjoy robust support from shareholders and stakeholders, thus possessing strong comprehensive debt repayment capabilities. Based on Bond B's credit rating, interest rate levels, and the issuer's debt repayment capacity, it is considered a viable investment option [10].

3.3 Calculation and Analysis

After the preliminary selection of bonds, the company needs to calculate the value of the bonds, a process typically conducted using the Discounted Cash Flow (DCF) model. In this model, investors are required to compute the present value of each period's cash flow for the two bonds and obtain three key parameters: the present value of cash flows (PV), the term (n), and the discount rate (y). Initially, investors may refer to the benchmark interest rates published by the central bank. The latest market rate quotation, the Loan Prime Rate (LPR), indicates a rate of 3.95% for terms exceeding five years. Hence, investors may consider this market rate the discount rate (y).

Based on these conditions, the company has decided to purchase two bonds on April 18, 2024. Both bonds have a face value of ¥100. Bond A carries a coupon rate of 4.23%, yielding a cash flow of ¥4.23 per period, while Bond B has a coupon rate of 4.77%, resulting in a cash flow of ¥4.77 per period. Bond A accrues interest from April 17, 2025, until April 17, 2030, spanning six periods, whereas Bond B accrues interest from October 29, 2024, until October 29, 2028, covering five periods. Investors can thus derive the respective terms (n) for both bonds. Subsequently, investors can compute the total present value of future cash flows for Bonds A and B and determine the present value of each period's cash flow for both bonds.

Through the Discounted Cash Flow (DCF) model in Equation (5).

$$PV_n = \frac{C_1}{(1+y)} + \frac{C_2}{(1+y)^2} + \frac{C_3}{(1+y)^3} + \cdots + \frac{C_n}{(1+y)^n} + \frac{F}{(1+y)^n} \tag{5}$$

Specific values can be calculated using Excel, as illustrated in the figures below in Table 1.

Table 1. Value of Bond A and Bond B

time	PVn	Bond A	Bond B
2025	PV1	4.07	4.59
2026	PV2	3.91	4.41
2027	PV3	3.77	4.25
2028	PV4	3.62	4.09
2029	PV5	3.49	86.32
2030	PV6	82.61	0
	Present value	101.47	103.66

Based on the preceding discussion, the formula for calculating bond duration is in Equation (6) & (7).

$$D = \sum t \times \frac{\frac{C_t}{1+y}^{t}}{PV} \tag{6}$$

$Wt{=}Ct1{+}ytPV$ #7

Based on the derivation of mathematical formulas, accurate calculation of the duration of two bonds requires the determination of the weight of each cash flow, which is the proportion of the present value of each cash flow to the total present value of the bond. Through this procedure, investors can compute the bond duration, which represents the weighted average time required for each cash flow payment.

So, investors can calculated the duration of bond A and bond B: D_A =5.427, D_B =4.571.

3.4 Proportion in Portfolio

In the subsequent step of determining the investment portfolio composition, investors need to consider the allocation between two types of bonds. In this regard, investors can employ the additivity principle of Macaulay duration. Based on the assumption mentioned earlier, if the proportion of bond A is represented by x, then the proportion of bond B would be (1-x). Consequently, investors can derive the following formula in Equation (8).

$$T = \sum_{i=1}^{n} w_i \times D_i \tag{7}$$

Where T denotes the composite duration of the portfolio, wi represents the proportion of bond i, and Di signifies the duration of bond i.

Considering a liability duration of five years and three months, namely T=5.25, upon substituting the respective numerical values, investors can solve for x to be approximately 79.32%. Thus, in constructing the bond portfolio, the proportion of bond A would be approximately 79.32%, while that of bond B would be approximately 20.67%.

3.5 Allocation of Money to Bonds

Ultimately, it is necessary to calculate the present value of future liabilities. Assuming a future liability amount of ¥10,000, its present value can be calculated using a discount rate (i.e., interest rate). Based on a discount rate of 0.0395, the future value of the ¥10,000 liability should be discounted to the present time as follows: ¥10,000/(1+0.0395)^7 = ¥7,624.8, which equals ¥7,624.8. Now, investors need to determine the purchase amount of each bond based on the proportion of the bond portfolio. The present value of the liabilities determines the amounts to be purchased for each bond. According to the model, the amount to be invested in Bond A is ¥6,048.8, and the amount for Bond B is ¥1,576

It is worth noting that since the company plans to purchase these two bonds on April 18, 2024, this is a future date. Therefore, investors cannot accurately ascertain the specific prices of these two bonds on April 18. Consequently, the purchase amounts calculated by investors are only estimates, and the actual purchase quantities will depend on the accurate market prices on April 18.

4 Conclusion

For corporate and individual investors, purchasing bonds is a common strategy to mitigate interest rate risk when facing future debt obligations. Bonds are renowned for their relatively lower risk and higher stability than other financial assets. Nevertheless, investors must pay particular attention to the mismatch between the debt maturity and the bond holding period, which can introduce interest rate risk. To address this concern, investors can leverage the additive nature of Macaulay duration by simultaneously acquiring various bonds. Investors can ascertain the bond portfolio's duration by employing the Discounted Cash Flow (DCF) method to compute their present values and subsequently utilizing the Macaulay duration formula. Ultimately, investors can effectively eliminate interest rate risk with precision by aligning the debt maturity with the duration of the bond portfolio, ensuring equivalence between the two.

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