DEBT SECURITIES

Topic 7: Interest rate risk measurement

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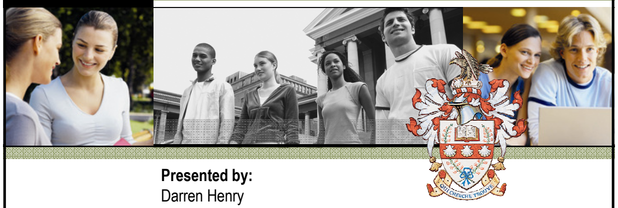

Presented by:
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Associate Professor of Finance
Department of Finance, La Trobe Business School

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Teaching arrangements for next week

- Lecture and tutorial arrangements for next week
  - There will be no lecture class next Wednesday 25th April 2012, due to the University closure for the Anzac Day Public Holiday
  - There will also be no tutorial classes next week, due to the Anzac Day Public Holiday and the majority of tutorial classes being scheduled on Wednesdays
- Assignment Workshop
  - In lieu of tutorial classes not being held, I have scheduled a one-hour workshop class relating to the subject assignment
  - This will be held on Thursday 26th April from 10.00am to 11.00am in the Glenn College Airport Lounge (on the second-floor of the main Glenn College building)
  - Will involve discussion of components and approaches relating to the assignment, including some quantitative elements, and question time

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Student learning objectives

7.1 Distinguish between the full valuation approach (the scenario analysis approach) and the duration/convexity approach for measuring interest rate risk, and explain the advantage of using the full valuation approach;

7.2 Describe the price volatility characteristics for option-free, callable, prepayable and putable bonds when interest rates change (including the concepts of “positive convexity” and “negative convexity”);

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Student learning objectives

7.3 Compute and interpret the effective duration of a bond, given information about how the bond's price will increase and decrease for given changes in interest rates, and compute the approximate percentage price change for a bond, given the bond's effective duration and a specified change in yield;

7.4 Distinguish among the alternative definitions of duration (modified, effective or option-adjusted, and Macaulay), and explain why effective duration is the most appropriate measure of interest rate risk for bonds with embedded options;

7.5 Compute the duration of a portfolio, given the duration of the bonds comprising the portfolio, and identify the limitations of portfolio duration;

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Student learning objectives

7.6 Describe the convexity measure of a bond and estimate a bond's percentage price change, given the bond's duration and convexity and a specified change in interest rates;

7.7 Distinguish between modified convexity and effective convexity;

7.8 Compute the price value of a basis point (PVBP), and explain its relationship to duration.

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References

- **Fabozzi F. J. (2007).** *Fixed Income Analysis*. John Wiley & Sons Inc. New Jersey. Chapter 7.

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Objective 7.1

Introduction

- We have already seen that the value of a bond varies indirectly with the level of interest rates
- If an investor in bonds has a long position, the value of the bond portfolio will fall if interest rates increase, and vice versa
- For a short position (e.g. an issuer of bonds), the value of the position will increase if interest rates increase, and vice versa – increasing interest rates will cause the value of bonds to fall, which in turn will cause the value of a short position to increase
- However, we need to know more than whether we are exposed to an increase or a decrease in interest rates – in order to manage interest rate risk we need to be able to measure it – to find out the *degree* of exposure to changes in interest rates

Interest rate risk measurement

Objective 7.1

Full valuation approach to risk measurement

- The **full-valuation** or **scenario analysis** approach to measuring interest rate risk values a bond or a portfolio of bonds both before and after a defined change in interest rates
- It requires the revaluation of the bonds under various scenarios, based on different possible changes in interest rates
- The difference in the valuations measures the effect on the value of the bond or portfolio of bonds that will result from the given change in interest rates
- This will provide a <u>precise</u> measure of the valuation consequences for an interest rate change scenario

Interest rate risk measurement

Example 7.1.1

Full valuation approach to risk measurement

- You hold a \$10 million position in a bond with a 9% coupon and a 20-year maturity, which is option free. Its current market price is 134.6722, which implies a yield to maturity of 6%.
- The value of the bond can be calculated using a formula or a financial calculator. Note that the valuation is based on semi-annual coupons.

To	Press	Display
Enter number of periods	40 [N]	N = 40.0000◂
Enter discount rate	3 [I/Y]	I/Y = 3.0000◂
Enter coupon payment	4.5 [+/–] [PMT]	PMT = -4.5000◂
Enter face value	100 [+/–] [FV]	FV = -100.0000◂
Compute present value	[CPT] [PV]	PV = 134.6722*

Interest rate risk measurement

Example 7.1.1

Full valuation approach to risk measurement

- We can then calculate the value of the bond assuming a yield to maturity equal to 6% plus 0.5%, 1% and 2%
- We can then find the difference in the value of the bond for each change, and divide by the current value of the bond to get the estimated sensitivity of the bond to a given change in interest rates
- Note the negative relationship between yield and price

Scenario	Yield change (bp)	New yield	New price	New market value (\$)	Sensitivity
1	50	6.5%	127.7605	12,776,050	-5.13%
2	100	7.0%	121.3551	12,135,510	-9.89%
3	200	8.0%	109.8964	10,989,640	-18.40%

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Example 7.1.2

Full valuation approach to risk measurement

- You hold a \$10 million position in a bond with a 9% coupon and a 20-year maturity, which is option free. Its current market price is 134.6722, which implies a yield to maturity of 6%.
- Additionally you hold a \$5 million position in a bond with a 6% coupon and a 5-year maturity, which is option free. Its current market price is 104.3760.
- **Calculate the percentage change in the market value of the portfolio under each of the following two scenarios: (1) assuming a 10 basis point change in 20-year rates and a 50 basis point change in 5 year rates, and (2) a 100 basis point change in 20-year rates and a 200 basis point change in 5-year rates**

Interest rate risk measurement

Example 7.1.2

Measuring yield curve risk

- Firstly, you will need to calculate the yield of the 5-year bond

To	Press	Display
Enter number of periods	10 [N]	N = 10.0000◂
Enter coupon payment	3 [+/–] [PMT]	PMT = -3.0000◂
Enter face value	100 [+/–] [FV]	FV = -100.0000◂
Enter present value	104.376 [PV]	PV = 104.3760◂
Compute discount rate	[CPT] [I/Y]	I/Y = 2.5000*

- This is the semi-annual yield, so the bond-equivalent yield is 5%
- Secondly, we will need to calculate the value of each bond, and sum the bond values, to obtain the portfolio value under each scenario
- We can then find the change in portfolio value under each scenario

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Example 7.1.2

Measuring yield curve risk

> Portfolio value before the changes in interest rates

Bond		Yield	Price	Market value ($)	
6% Bond		5%	104.3760	5,218,800	
9% Bond		6%	134.6722	13,467,220	
				18,686,020	

> Scenario One

Bond	Yield change (bp)	New yield	New price	New market value ($)	Sensitivity
6% Bond	50	5.5%	102.1600	5,108,000	
9% Bond	10	6.1%	133.2472	13,324,720	
				18,432,720	-1.36%

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Example 7.1.2

Measuring yield curve risk

> Portfolio value before the changes in interest rates

Bond		Yield	Price	Market value ($)	
6% Bond		5%	104.3760	5,218,800	
9% Bond		6%	134.6722	13,467,220	
				18,686,020	

> Scenario Two

Bond	Yield change (bp)	New yield	New price	New market value ($)	Sensitivity
6% Bond	200	7.0%	95.8417	4,792,085	
9% Bond	100	7.0%	121.3551	12,135,510	
				16,927,595	-9.41%

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Objective 7.1

Full valuation approach to risk measurement

> Advantages of the full-valuation approach
  - It allows for the analysis not only of the sensitivity of a portfolio of bonds to interest rate risk but also to yield curve risk (the risk that yields associated with different maturities will not change by the same amount)

> Disadvantages of the full-valuation approach
  - It can be very time consuming

> In many situations it would be preferable to have one simple measure that can be used to get an idea of how bond prices will change if rates change in a parallel fashion, rather than having to revalue an entire portfolio

> Before introducing such a measure, we need to consider the price volatility characteristics of bonds

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Objective 7.2

Price volatility properties of option-free bonds

> Four properties of option-free bonds
1. Although the price moves in the opposite direction from the change in yield, the percentage price change is not the same for all bonds
2. For small changes in the yield, the percentage price change for a given bond is roughly the same, whether the yield increases or decreases
3. For large changes in yield, the percentage price change is not the same for an increase in yield as it is for a decrease in yield
4. For a given large change in yield, the percentage price increase is greater than the percentage price decrease – this is referred to as **convexity**

> An additional property of option-free bonds
  - The greater is a bond's convexity, the greater is the difference between the percentage price increase and the percentage price decrease for a given large change in the yield

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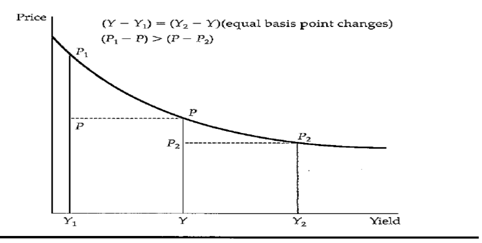
Objective 7.2

Price volatility properties of option-free bonds

EXHIBIT 72-7 Graphical Illustration of Properties 3 and 4 for an Option-Free Bond



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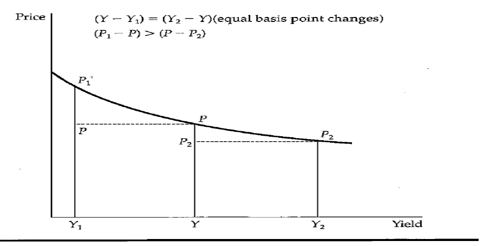
Objective 7.2

Price volatility properties of option-free bonds

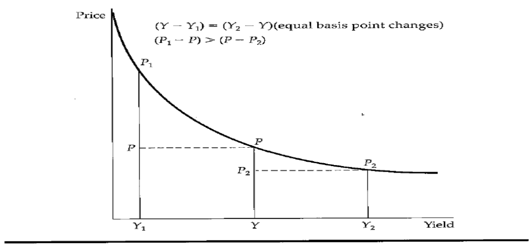
EXHIBIT 72-8 Impact of Convexity on Property 4: Less Convex Bond



Objective 7.2

Price volatility properties of option-free bonds

EXHIBIT 72-9 Impact of Convexity on Property 4: Highly Convex Bond



Objective 7.2

Price volatility properties of bonds with embedded options

- The price of a bond with an embedded option has two components – the value of an equivalent option-free bond plus or minus the value of the embedded option
- The two most common embedded options are call (or prepayment) options and put options
- As interest rates fall, an issuer may call (or prepay) the debt obligation, and as interest rates increase an investor may put the bond
- A call option is of value to the issuer, and therefore reduces the value of the bond from the point of view of the investor
- A put option is of value to the investor, and therefore increases the value of the bond from the point of view of the investor

Objective 7.2

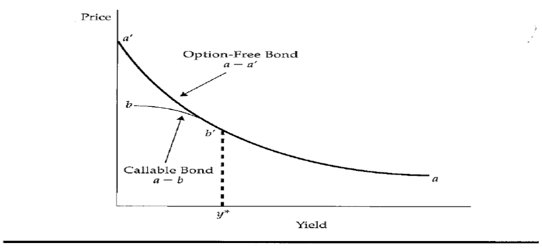
Price volatility properties of bonds with a call/prepay option

- A callable bond may be called or prepaid by the issuer
- A call or prepay option embedded in a bond is likely only to be exercised if the market yield falls below the coupon rate of the bond as it is only then that the issuer, who holds the option, can refinance at a lower rate
- Since the bond is unlikely to be called if the market yield is higher than the coupon rate, the price-yield relationship for yields greater than the coupon rate will mirror that of an option-free bond
- This means that properties 1-4 hold for a bond with an embedded call option where the market yield is greater than the coupon rate, ie it is said to exhibit **positive convexity**

Objective 7.2

Price volatility properties of bonds with a call/prepay option

EXHIBIT 72-10 Price/Yield Relationship for a Callable Bond and an Option-Free Bond



Objective 7.2

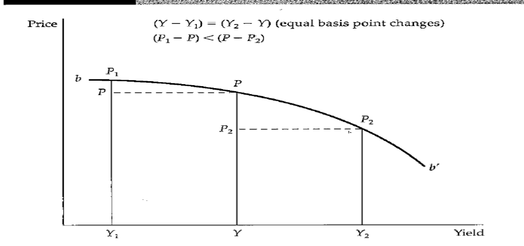
Price volatility properties of bonds with a call/prepay option

- As the value of the embedded option is a function of the probability that it will be exercised, the value of the embedded call option will increase the further the market yield falls below the coupon rate
- In this situation the option is said to be "in-the-money"
- The more valuable the call option to the issuer, the lower the price of the bond
- This has the effect of negating property 4, because when the market yield is less than the coupon rate, the price of the bond rises by less for a fall in the market rate than the fall in the bond price for an increase in the market rate
- Where the market yield is less than the coupon rate a bond with an embedded call option is said to exhibit **negative convexity**

Objective 7.2

Price volatility properties of bonds with a call/prepay option

EXHIBIT 72-11 Negative Convexity Region of the Price/Yield Relationship for a Callable Bond



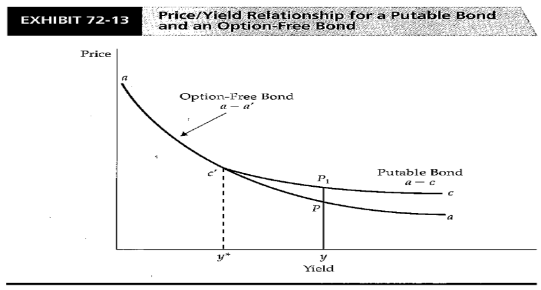
Objective 7.2

Price volatility properties of bonds with a put option

> A putable bond may be redeemed by the bondholder, typically at par
> If market yields rise such that the bond's price falls below par (i.e. the market yield is greater than the bond's coupon rate) then the investor can redeem the bond's value at par
> The value of the putable bond is equal to the value of an option free bond *plus* the value of the put-option; hence, the difference between the value of a putable bond and an option free bond for a given yield is the value of the put option
> When market yields are less than the coupon rate the value of the putable bond equals the value of an option free bond
> When the market yield is greater than the coupon rate, the option increases in value, increasing the value of the bond – the bond's convexity, though positive, will be less than for an option-free bond

Objective 7.2

Price volatility properties of bonds with a call/prepay option



Objective 7.3

Effective duration

> Duration is the measure of the approximate price sensitivity of a bond to interest rate changes
> Specifically, it is the approximate percentage change in price for a 100 basis point change in interest rates

$$\text{Duration} = \frac{V_- - V_+}{2(V_0)(\Delta y)} \qquad \text{(DBS 7.3.1)}$$

where

Δy = change in yield in decimal (basis points) form
V_0 = initial price
V_- = price if yield decreases by Δy
V_+ = price if yield increases by Δy

Example 7.3.1

Duration

?

> You hold a $10 million position in a bond with a 9% coupon and a 20-year maturity, which is option free. Its current market price is 134.6722, which implies a yield to maturity of 6%.

> **Calculate the duration of the bond based on a change in yield of 20 basis points.**

Example 7.3.1

Duration

> We need to calculate the value of the bond for a 20 basis point increase and a 20 basis point decrease in the yield:

Δy = 0.002
V_0 = 134.6722
V_- = 137.5888
V_+ = 131.8439

> Duration is calculated as follows:

$$Duration = \frac{V_- - V_+}{2(V_0)(\Delta y)} = \frac{137.5888 - 131.8439}{2(134.6722)(0.002)} = 10.66$$

Objective 7.3

Approximating the percentage price change using duration

> The percentage price change can be approximated for a given change in yield, Δy, using duration

$$\text{Approx. price change (\%)} = -\text{Duration} \times \Delta y \times 100 \qquad \text{(DBS 7.3.2)}$$

where

Δy = the change in yield for which the price change is to be approximated

> Note that this method only works for small changes in yield, which is consistent with Property 2 (noted above)
> Note also that the approximate price change is estimated to be the same, regardless of whether yield rises or falls, which is inconsistent with Properties 3 and 4

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Example 7.3.2

Approximating percent price change using duration

> You hold a $10 million position in a bond with a 9% coupon and a 20-year maturity, which is option free. Its current market price is 134.6722, which implies a yield to maturity of 6%.

> **Calculate and compare the approximate price changes for a change in yield of 10 and 200 basis points.**

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Example 7.3.2

Approximating percent price change using duration

> 10 bp increase in yield

$$\text{Approx. price change}(\%) = -\text{Duration} \times \Delta y \times 100$$
$$= -10.66 \times (0.001) \times 100 = -1.066\%$$

> 10 bp decrease in yield

$$\text{Approx. price change}(\%) = -\text{Duration} \times \Delta y \times 100$$
$$= -10.66 \times (-0.001) \times 100 = +1.066\%$$

> 200 bp increase in yield

$$\text{Approx. price change}(\%) = -\text{Duration} \times \Delta y \times 100$$
$$= -10.66 \times (0.02) \times 100 = -21.32\%$$

> 200 bp decrease in yield

$$\text{Approx. price change}(\%) = -\text{Duration} \times \Delta y \times 100$$
$$= -10.66 \times (-0.02) \times 100 = +21.32\%$$

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Example 7.3.2

Approximating percent price change using duration

> Note that the estimated price is close to the actual price for a small change in yields, but is quite different for large changes in yields

> Note that for large changes in yield the approximation always underestimates the price

Yield change (bp)	Initial price	New price based on duration	New price (actual)	Pct change based on duration	Percent change (actual)
+10	134.6722	133.2366	133.2472	-1.066	-1.06
-10	134.6722	136.1078	136.1193	+1.066	+1.07
+200	134.6722	105.9601	109.8964	-21.32	-18.40
-200	134.6722	163.3843	168.3887	+21.32	+25.04

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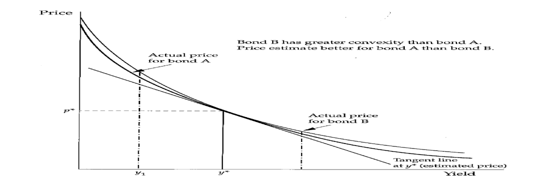
Objective 7.3

Approximating the percentage price change using duration

> The underestimation of the price change using duration is the result of the convexity of the price-yield relationship

> The more convex the relationship the larger will be the error in calculating the price change using duration, for large yield changes

EXHIBIT 72-16 Estimating the New Price for a Large Yield Change for Bonds with Different Convexities



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Objective 7.4

Alternative definitions of duration

> An alternative to the effective duration that we have been using is **modified duration**

> Modified duration is the approximate percentage change in a bond's price for a 100 basis point change in yield *assuming that the bond's expected cash flows do not change when the yield changes*

> This means that, in calculating the values of V_- and V_+ in formula (DBS 7.3.1), the same cash flows used to calculate V_0 are used

> Therefore the change in the bond's price when the yield is changed is due solely to discounting cash flows at the new yield level

> This makes sense for an option-free bond, but for securities with embedded options a change in yield may significantly alter the expected cash flows

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Objective 7.4

Alternative definitions of duration

> Modified duration can be compared to effective duration, which is undertaken using a model which takes into account how changes in the yield will affect the expected cash flows of a bond with an embedded option

> Effective duration therefore takes into account:
  - The discounting at different interest rates, and
  - How expected cash flows may change

> The difference between modified duration and effective duration of bonds with embedded options can be significant; hence effective duration should be used for bonds with embedded options

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Objective 7.4

Alternative definitions of duration

- It is worth comparing modified duration with **Macaulay duration**
- Macaulay duration is calculated using the following formula:

$$\text{Macaulay Duration} = \left[\frac{1\times PVCF_1 + 2\times PVCF_2 + \ldots + n\times PVCF_n}{k\times \text{Price}}\right] \qquad \text{(DBS 7.4.1)}$$

where

k = number of periods per annum

n = number of periods until maturity

$PVCF_t$ = present value of a cash flow in period *t* discounted at the YTM

- Modified duration can be calculated as: $\dfrac{\text{Macaulay Duration}}{(1+YTM/k)}$

Objective 7.5

Portfolio duration

- A portfolio's duration may be obtained by calculating the weighted average duration of the bonds in the portfolio
- The weight is the proportion of the portfolio that a security comprises:

$$\text{Portfolio Duration} = w_1D_1 + w_2D_2 + w_3D_3 + \ldots + w_kD_k$$

where

$w_i = \dfrac{\text{market value of bond } i}{\text{market value of portfolio}}$

D_i = duration of bond i

k = number of bonds in the portfolio

Example 7.5.1

Portfolio duration

- Consider the following portfolio

Bond	Price ($)	Yield (%)	Par amount	Market value	Duration
10%, 5-year	100.0000	10	$4 million	$4,000,000	3.861
8%, 15-year	84.6275	10	5 million	4,231,375	8.047
14%, 30-year	137.8586	10	1 million	1,378,586	9.168

$$\text{Portfolio Duration} = w_1D_1 + w_2D_2 + w_3D_3 + \ldots + w_kD_k$$

$$= \left(\frac{4{,}000{,}000}{9{,}609{,}961}\right)(3.861) + \left(\frac{4{,}231{,}375}{9{,}609{,}961}\right)(8.047) + \left(\frac{1{,}378{,}586}{9{,}609{,}961}\right)(9.168)$$

$$= 6.466$$

Objective 7.6

Convexity

- **Duration** is a linear approximation of the percentage price change in the value of a bond for a small change in yield
- The **convexity adjustment** is used to improve on duration by approximating the change in price that is not explained by duration
- The formula for the convexity adjustment to the percentage price change is:

$$\text{Convexity Adjustment} = C\times(\Delta y^*)^2 \times 100 \qquad \text{(DBS 7.6.1)}$$

where:

Δy^* = the change in yield for which the percentage change is sought

$$C = \frac{V_+ + V_- - 2V_0}{2V_0(\Delta y)^2} \qquad \text{(DBS 7.6.2)}$$

Example 7.6.1

Convexity

- You hold a $10 million position in a bond with a 9% coupon and a 20-year maturity, which is option free. Its current market price is 134.6722, which implies a yield to maturity of 6%.

- **Calculate the convexity-adjusted duration of the bond based on a 200 basis point change in yields.**

Example 7.6.1

Convexity

- We know from example 7.3.1 (using a bond with a yield of 6% and a rate shock of 20 basis points (Δy = 0.002)):

V_0 = 134.6722

V_+ = 131.8439

V_- = 137.5888

- We can substitute these values into the formula for C:

$$C = \frac{131.8439 + 137.5888 - 2(134.6722)}{2(134.6722)(0.002)^2} = 81.95$$

- To find the convexity adjustment for a 200 basis point shift in rates:

$$CA = 81.95\times(0.02)^2 \times 100 = 3.28\%$$

Interest rate risk measurement

Example 7.6.1

Convexity

- We can sum the duration and the convexity adjustment to calculate the estimated price change for a rise in yield from 6% to 8%:
  - Estimated percentage price change using duration = –21.32%
  - Convexity adjustment = +3.28%
  - Total estimated percentage price change = –18.04%
- Alternatively we can sum the duration and the convexity adjustment to calculate the estimated price change for a fall in yield from 6% to 4%:
  - Estimated percentage price change using duration = +21.32%
  - Convexity adjustment = +3.28%
  - Total estimated percentage price change = +24.60%

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Objective 7.7

Modified convexity and effective convexity

- As with duration, the convexity adjustment can be calculated either taking into account changes in cash flow associated with the changes in yields or ignoring such cash flow changes
  - **Modified convexity adjustment** assumes that the expected cash flows do not change as a result of changes in yields
  - **Effective convexity adjustment** assumes that the expected cash flows may change as a result of changes in yields and adjusts for any changes
- There is little difference between the modified and effective convexity adjustments for option-free bonds
- However for bonds with embedded options the difference can be significant

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Objective 7.8

Price value of a basis point (PVBP)

- Some managers use another measure of the price volatility of a bond to quantify interest rate risk – the **price value of a basis point**
- This is also referred to as **the dollar value of an 01** (DV01),
- The PVBP measures the absolute value of the change in the price of a bond for a 1 basis point change in yield

$$PVBP = V_0 - V_{0.0001} \qquad \text{(DBS 7.8.1)}$$

- PVBP is related to duration, such that given the initial price and the approximate percentage price change for 1 basis point, we can compute the change in price for a 1 basis point change in rates using the approximate percentage price change formula (DBS 7.3.2)

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Interest rate risk measurement

Example 7.8.1

Price value of a basis point (PVBP)

- You hold a $10 million position in a bond with a 9% coupon and a 20-year maturity, which is option free. Its current market price is 134.6722, which implies a yield to maturity of 6%.
- In order to use PBVP, we need to recalculate the price of the bond after a 1 basis point increase in the yield
- If the yield increases to 6.01%, the price of the bond falls to 134.5287
- The PVBP based on formula DBS 7.8.1 is given by:

$$\begin{aligned} PVBP &= V_0 - V_{0.0001} \\ &= \$134.6722 - 134.5287 = \$0.1435 \end{aligned}$$

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Example 7.8.1

Price value of a basis point (PVBP)

- You hold a $10 million position in a bond with a 9% coupon and a 20-year maturity, which is option free. Its current market price is 134.6722, which implies a yield to maturity of 6%.
- The approximate price change for a 1 basis point change in yield, based on formula (DBS 7.3.2) (and ignoring the negative):

$$\begin{aligned} \text{Approx. price change}(\%) &= -\text{Duration} \times \Delta y \times 100 \\ &= 10.66 \times (0.0001) \times 100 = +0.1066\% \end{aligned}$$

- Given the initial price of 134.6722, the dollar price change can be estimated:

$$0.1066\% \times 134.6722 = \$0.1436$$

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Interest rate risk measurement

Tutorial assessment task 3 in Tutorial 7 (in two weeks time)

- Tutorial assessment task 3 will relate to the Credit Analysis topic covered in Lecture 6 and Tutorial 6. This will require you to:
  - Identifying relationships between different financial ratios and overall trends in ratios over time for a specific firm, and suggest implications from this identification.
  - Apply a credit scoring model using financial ratios to identify the potential bankruptcy (default) risk of a firm (The full equation and variable details for the credit scoring model will be provided).
  - Determine the credit worthiness of the firm and assign a suitable credit rating based on the firm's financial ratios, financial ratio information for comparable firms and the credit scoring analysis.

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