Chapter 10

Bond Prices and Yields
Bond Prices and Yields

• Our goal in this chapter is to understand the relationship between bond prices and yields.

• In addition, we will examine some fundamental tools that fixed-income portfolio managers use when they assess bond risk.
A **Straight bond** is an IOU that obligates the issuer of the bond to pay the holder of the bond:
- A fixed sum of money (called the principal, par value, or face value) at the bond’s maturity, and sometimes
- Constant, periodic interest payments (called coupons) during the life of the bond

**U.S. Treasury bonds are straight bonds.**

**Special features may be attached**
- Convertible bonds
- Callable bonds
- Putable bonds
Two basic yield measures for a bond are its *coupon rate* and its *current yield*.

**Coupon rate** = \( \frac{\text{Annual coupon}}{\text{Par value}} \)

**Current yield** = \( \frac{\text{Annual coupon}}{\text{Bond price}} \)
• The price of a bond is found by adding together the present value of the bond’s coupon payments and the present value of the bond’s face value.

• The Yield to maturity (YTM) of a bond is the discount rate that equates the today’s bond price with the present value of the future cash flows of the bond.
The Bond Pricing Formula

- *The price of a bond is found by adding together the present value of the bond’s coupon payments and the present value of the bond’s face value.*

- The formula is:

  \[
  \text{Bond Price} = \frac{C}{\text{YTM}} \left[ 1 - \frac{1}{\left(1 + \frac{\text{YTM}}{2}\right)^{2M}} \right] + \frac{\text{FV}}{\left(1 + \frac{\text{YTM}}{2}\right)^{2M}}
  \]

- In the formula, \( C \) represents the **annual** coupon payments (in $), \( \text{FV} \) is the face value of the bond (in $), and \( M \) is the maturity of the bond, measured in years.
Example: Using the Bond Pricing Formula

- What is the price of a straight bond with: $1,000 face value, coupon rate of 8%, YTM of 9%, and a maturity of 20 years?

\[
\text{Bond Price} = \frac{C}{\text{YTM}} \left[ 1 - \frac{1}{\left(1 + \frac{\text{YTM}}{2}\right)^{2M}} \right] + \frac{\text{FV}}{\left(1 + \frac{\text{YTM}}{2}\right)^{2M}}
\]

\[
\frac{80}{0.09} \left[ 1 - \frac{1}{\left(1 + \frac{0.09}{2}\right)^{2 \times 20}} \right] + \frac{1000}{\left(1 + \frac{0.09}{2}\right)^{2 \times 20}}
\]

\[=(888.89 \times 0.82807) + 171.93\]

\[= $907.99.\]
Example: Calculating the Price of this Straight Bond Using *Excel*

- *Excel* has a function that allows you to price straight bonds, and it is called **PRICE**.

  \[
  \text{=PRICE(“Today”,“Maturity”,Coupon Rate,YTM,100,2,3)}
  \]

- Enter “Today” and “Maturity” in quotes, using mm/dd/yyyy format.
- Enter the Coupon Rate and the YTM as a decimal.
- The "100" tells *Excel* to us $100 as the par value.
- The "2" tells *Excel* to use semi-annual coupons.
- The "3" tells *Excel* to use an actual day count with 365 days per year.

Note: *Excel* returns a price per $100 face.
Premium and Discount Bonds, I.

- Bonds are given names according to the relationship between the bond’s selling price and its par value.
  - **Premium bonds**: price > par value  
    YTM < coupon rate
  - **Discount bonds**: price < par value  
    YTM > coupon rate
  - **Par bonds**: price = par value  
    YTM = coupon rate
Premium and Discount Bonds, II.

FIGURE 10.1 Premium, Par, and Discount Bond Prices

The graph illustrates the relationship between bond prices and time to maturity for bonds with premium, par, and discount values. As the time to maturity decreases, the bond prices approach par, with premium bonds increasing and discount bonds decreasing in value.

- **Premium** bond prices (over par) increase as the time to maturity decreases.
- **Par** bond prices remain constant at par.
- **Discount** bond prices (below par) decrease as the time to maturity decreases.

Bond prices are measured in percent of par, and time to maturity is measured in years.
Premium and Discount Bonds, III.

• In general, when the coupon rate and YTM are held constant:

  *for premium bonds*: the longer the term to maturity, the greater the premium over par value.

  *for discount bonds*: the longer the term to maturity, the greater the discount from par value.
Relationships among Yield Measures

*for premium bonds*: 
coupon rate > current yield > YTM

*for discount bonds*: 
coupon rate < current yield < YTM

*for par value bonds*: 
coupon rate = current yield = YTM
Calculating Yield to Maturity, I.

- Suppose we know the current price of a bond, its coupon rate, and its time to maturity. How do we calculate the YTM?

- We can use the straight bond formula, trying different yields until we come across the one that produces the current price of the bond.

\[
\frac{\$907.99}{YTM} = \frac{\$80}{\left[1 - \frac{1}{\left(1 + \frac{YTM}{2}\right)^{2 \times 20}}\right]} + \frac{\$1,000}{\left(1 + \frac{YTM}{2}\right)^{2 \times 20}}
\]

- This is tedious. So, to speed up the calculation, financial calculators and spreadsheets are often used.
Calculating Yield to Maturity, II.

• We can use the YIELD function in Excel:

   =YIELD("Today","Maturity",Coupon Rate,Price,100,2,3)

• Enter “Today” and “Maturity” in quotes, using mm/dd/yyyy format.
• Enter the Coupon Rate as a decimal.
• Enter the Price as per hundred dollars of face value.
• Note: As before,
  – The "100" tells Excel to us $100 as the par value.
  – The "2" tells Excel to use semi-annual coupons.
  – The "3" tells Excel to use an actual day count with 365 days per year.

• Using dates 20 years apart, a coupon rate of 8%, a price (per hundred) of $90.80, give a YTM of 0.089999, or 9%.
A Quick Note on Bond Quotations, I.

- We have seen how bond prices are quoted in the financial press, and how to calculate bond prices.

- Note: If you buy a bond between coupon dates, you will receive the next coupon payment (and might have to pay taxes on it).

- However, when you buy the bond between coupon payments, you must compensate the seller for any accrued interest.
A Quick Note on Bond Quotations, II.

- The convention in bond price quotes is to ignore accrued interest.
  - This results in what is commonly called a **clean price** (i.e., a quoted price net of accrued interest).
  - Sometimes, this price is also known as a **flat price**.

- The price the buyer actually pays is called the **dirty price**.
  - This is because accrued interest is added to the **clean price**.
  - Note: The price the buyer actually pays is sometimes known as the **full price**, or **invoice price**.
Callable Bonds

• Thus far, we have calculated bond prices assuming that the actual bond maturity is the original stated maturity.

• However, most bonds are **callable bonds**.

• A **callable bond** gives the issuer the option to buy back the bond at a specified **call price** anytime after an initial **call protection period**.

• Therefore, for callable bonds, YTM may not be useful.
Yield to Call

1. **Yield to call (YTC)** is a yield measure that assumes a bond will be called at its earliest possible call date.

2. The formula to price a callable bond is:

   \[
   \text{Callable Bond Price} = \frac{C}{YTC} \left(1 - \frac{1}{(1 + \frac{YTC}{2})^{2T}}\right) + \frac{CP}{(1 + \frac{YTC}{2})^{2T}}
   \]

3. In the formula, \(C\) is the **annual** coupon (in $), \(CP\) is the call price of the bond, \(T\) is the time (in years) to the earliest possible call date, and \(YTC\) is the yield to call, with semi-annual coupons.

4. As with straight bonds, we can solve for the YTC, if we know the price of a callable bond.
Interest Rate Risk

- Holders of bonds face **Interest Rate Risk**.

- **Interest Rate Risk** is the possibility that changes in interest rates will result in losses in the bond’s value.

- The yield actually earned or “realized” on a bond is called the **realized yield**.

- Realized yield is almost never exactly equal to the **yield to maturity**, or **promised yield**.
Interest Rate Risk and Maturity

**FIGURE 10.2** Bond Prices and Yields

- **20-year maturity**
- **5-year maturity**

![Graph showing bond prices and yields over different maturities](image)
Malkiel’s Theorems, I.

1️⃣ Bond prices and bond yields move in opposite directions.
   - As a bond’s yield increases, its price decreases.
   - Conversely, as a bond’s yield decreases, its price increases.

2️⃣ For a given change in a bond’s YTM, the longer the term to maturity of the bond, the greater the magnitude of the change in the bond’s price.
Malkiel’s Theorems, II.

③ For a given change in a bond’s YTM, the size of the change in the bond’s price increases at a diminishing rate as the bond’s term to maturity lengthens.

④ For a given change in a bond’s YTM, the absolute magnitude of the resulting change in the bond’s price is inversely related to the bond’s coupon rate.

⑤ For a given absolute change in a bond’s YTM, the magnitude of the price increase caused by a decrease in yield is greater than the price decrease caused by an increase in yield.
## Bond Prices and Yields

### SPREADSHEET ANALYSIS

<table>
<thead>
<tr>
<th>A</th>
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<td>Calculating the Price of a Coupon Bond</td>
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<td>$10.6775 = PRICE(&quot;3/30/2006&quot;, &quot;3/30/2026&quot;, 0.08, 0.07, 100, 2, 3)</td>
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<td>For a bond with $1,000 face value, multiply the price by 10 to get $1,106.78.</td>
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Duration

• Bondholders know that the price of their bonds change when interest rates change. But,
  – How big is this change?
  – How is this change in price estimated?

• **Macaulay Duration, or Duration**, is the name of concept that helps bondholders measure the sensitivity of a bond price to changes in bond yields. That is:

\[
Pct. \text{ Change in Bond Price} \approx -\text{Duration} \times \frac{\text{Change in YTM}}{\left(1 + \frac{\text{YTM}}{2}\right)}
\]

→ **Two bonds with the same duration, but not necessarily the same maturity, will have approximately the same price sensitivity to a (small) change in bond yields.**
Example: Using Duration

• Example: Suppose a bond has a Macaulay Duration of 11 years, and a current yield to maturity of 8%.

• If the yield to maturity increases to 8.50%, what is the resulting percentage change in the price of the bond?

\[
\text{Pct. Change in Bond Price} \approx -11 \times \frac{(0.085 - 0.08)}{\left(1 + \frac{0.08}{2}\right)}
\]

\[\approx -5.29\%.
\]
Modified Duration

- Some analysts prefer to use a variation of Macaulay’s Duration, known as Modified Duration.

\[
\text{Modified Duration} = \frac{\text{Macaulay Duration}}{\left(1 + \frac{\text{YTM}}{2}\right)}
\]

- The relationship between percentage changes in bond prices and changes in bond yields is approximately:

\[
P\text{ct. Change in Bond Price} \approx - \text{Modified Duration} \times \text{Change in YTM}
\]
Calculating Macaulay’s Duration

- Macaulay’s duration values are stated in years, and are often described as a bond’s *effective maturity*.

- *For a zero-coupon bond*, duration = maturity.

- *For a coupon bond*, duration = a weighted average of individual maturities of all the bond’s separate cash flows, where the weights are proportionate to the present values of each cash flow.
Calculating Macaulay’s Duration

• In general, for a bond paying constant semiannual coupons, the formula for Macaulay’s Duration is:

\[
\text{Duration} = \frac{1 + \frac{\text{YTM}}{2}}{\text{YTM}} - \frac{1 + \frac{\text{YTM}}{2} + M(\text{C} - \text{YTM})}{\text{YTM} + \text{C} \left( \left(1 + \frac{\text{YTM}}{2}\right)^{2M} - 1 \right)}
\]

• In the formula, C is the annual coupon rate, M is the bond maturity (in years), and YTM is the yield to maturity, assuming semiannual coupons.
Calculating Macaulay’s Duration for Par Bonds

• If a bond is selling for par value, the duration formula can be simplified to:

\[
\text{Par Value Bond Duration} = \frac{1 + \frac{\text{YTM}}{2}}{\text{YTM}} \left[ 1 - \frac{1}{\left(1 + \frac{\text{YTM}}{2}\right)^{2\text{M}}} \right]
\]
Calculating Duration Using Excel

- We can use the `DURATION` and `MDURATION` functions in Excel to calculate Macaulay Duration and Modified Duration.

- The Excel functions use arguments like we saw before:

  \[=DURATION(\text{"Today"},\text{"Maturity"},\text{Coupon Rate},\text{YTM},2,3)\]

- You can verify that a 5-year bond, with a 9% coupon and a 7% YTM has a Duration of 4.17 and a Modified Duration of 4.03.
Calculating Macaulay’s Duration

A Treasury bond traded on March 30, 2006, matures in 12 years on March 30, 2018. Assuming a 6 percent coupon rate and a 7 percent yield to maturity, what are the Macaulay and Modified durations of this bond? Hint: Use the Excel functions DURATION and MDURATION.

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<td>8.561</td>
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<td>8.272</td>
<td>= MDURATION(&quot;3/30/2006&quot;,&quot;3/30/2018&quot;,0.06,0.07,2,3)</td>
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Duration Properties

① All else the same, the longer a bond’s maturity, the longer is its duration.

② All else the same, a bond’s duration increases at a decreasing rate as maturity lengthens.

③ All else the same, the higher a bond’s coupon, the shorter is its duration.

④ All else the same, a higher yield to maturity implies a shorter duration, and a lower yield to maturity implies a longer duration.
Properties of Duration

**FIGURE 10.3** Bond Duration and Maturity

The graph depicts the relationship between bond duration and bond maturity for different coupon rates. The x-axis represents bond maturity (years), while the y-axis represents bond duration (years). The graph includes lines for different coupon rates: 0%, 5%, 10%, and 15%. As maturity increases, the duration also increases, with higher coupon rates having a stronger effect on duration.

- **0% coupon** line: Steepest curve, indicating the least duration increase with maturity.
- **5% coupon** line: Moderately steep, showing a moderate increase in duration.
- **10% coupon** line: Softer curve, indicating a smaller increase in duration.
- **15% coupon** line: Steepest among the lower rates, showing a significant increase in duration.

This visualization helps in understanding how bond durations vary with different coupon rates and maturities.
Bond Risk Measures Based on Duration, I.

- Dollar Value of an 01: Measures the change in bond price from a one basis point change in yield.

  \[
  \text{Dollar Value of an 01} \approx - \text{Modified Duration} \times \text{Bond Price} \times 0.01
  \]

- Yield Value of a 32\textsuperscript{nd}: Measures the change in yield that would lead to a 1/32\textsuperscript{nd} change in the bond price.

  \[
  \text{Yield Value of a 32nd} \approx \frac{1}{32 \times \text{Dollar Value of an 01}}
  \]

In both cases, the bond price is per $100 face value.
Suppose a bond has a modified duration of 8.27 years.
- What is the dollar value of an 01 for this bond (per $100 face value)?
- What is the yield value of a 32\textsuperscript{nd} (per $100 face value)?

First, we need the price of the bond, which is $91.97. Verify using:
- YTM = 7%
- Coupon = 6%
- Maturity = 12 Years.

The **Dollar Value of an 01** is $0.07606, which says that if the YTM changes one basis point, the bond price changes by 7.6 cents.

The **Yield Value of a 32\textsuperscript{nd]** is .41086, which says that a yield change of .41 basis points changes the bond price by 1/32\textsuperscript{nd} (3.125 cents).
Dedicated Portfolios

- A **Dedicated Portfolio** is a bond portfolio created to prepare for a future cash payment, e.g. pension funds.

- The date the payment is due is commonly called the portfolio’s **target date**.
• **Reinvestment Rate Risk** is the uncertainty about the value of the portfolio on the target date.

• Reinvestment Rate Risk stems from the need to reinvest bond coupons at yields not known in advance.

• **Simple Solution**: purchase zero coupon bonds.

• **Problem with Simple Solution**:
  – U.S. Treasury STRIPS are the only zero coupon bonds issued in sufficiently large quantities.
  – STRIPS have lower yields than even the highest quality corporate bonds.
Price Risk

- **Price Risk** is the risk that bond prices will decrease.
- Price risk arises in dedicated portfolios when the target date value of a bond is not known with certainty.
Price Risk versus Reinvestment Rate Risk

- For a dedicated portfolio, interest rate **increases** have two effects:
  - Increases in interest rates **decrease** bond prices, but
  - Increases in interest rates **increase** the future value of reinvested coupons

- For a dedicated portfolio, interest rate **decreases** have two effects:
  - Decreases in interest rates **increase** bond prices, but
  - Decreases in interest rates **decrease** the future value of reinvested coupons
Immunization

- **Immunization** is the term for constructing a dedicated portfolio such that the uncertainty surrounding the target date value is minimized.

- It is possible to engineer a portfolio such that price risk and reinvestment rate risk offset each other (just about entirely).
Immunization by Duration Matching

- A dedicated portfolio can be immunized by *duration matching* - matching the duration of the portfolio to its target date.

- Then, the impacts of price and reinvestment rate risk will almost exactly offset.

- This means that interest rate changes will have a minimal impact on the target date value of the portfolio.
Immunization by Duration Matching

**FIGURE 10.4** Bond Price and Reinvestment Rate Risk

![Graph showing bond price and reinvestment rate risk](image)

- Portfolio value ($ millions)
- Time (years)
- Yields: 8%, 6%, 10%

The graph illustrates how different yields affect the portfolio value over time.
Dynamic Immunization

- **Dynamic immunization** is a periodic rebalancing of a dedicated bond portfolio for the purpose of maintaining a duration that matches the target maturity date.

- The advantage is that the reinvestment risk caused by continually changing bond yields is greatly reduced.

- The drawback is that each rebalancing incurs management and transaction costs.
Useful Internet Sites

- [www.bondmarkets.com](http://www.bondmarkets.com) (check out the bonds section)
- [www.bondpage.com](http://www.bondpage.com) (treasury bond prices and yields search tool)
- [www.jamesbaker.com](http://www.jamesbaker.com) (a practical view of bond portfolio management)
- [www.bondsonline.com](http://www.bondsonline.com) (bond basics and current market data)
- [www.investinginbonds.com](http://www.investinginbonds.com) (bond basics and current market data)
- [www.bloomberg.com](http://www.bloomberg.com) (for information on government bonds)
Chapter Review, I.

- **Bond Basics**
  - Straight Bonds
  - Coupon Rate and Current Yield

- **Straight Bond Prices and Yield to Maturity**
  - Straight Bond Prices
  - Premium and Discount Bonds
  - Relationships among Yield Measures
Chapter Review, II.

- More on Yields
  - Calculating Yields
  - Yield to Call

- Interest Rate Risk and Malkiel’s Theorems
  - Promised Yield and Realized Yield
  - Interest Rate Risk and Maturity
  - Malkiel’s Theorems
Chapter Review, III.

- Duration
  - Macaulay Duration
  - Modified Duration
  - Calculating Macaulay’s Duration
  - Properties of Duration

- Dedicated Portfolios and Reinvestment Risk
  - Dedicated Portfolios
  - Reinvestment Risk

- Immunization
  - Price Risk versus Reinvestment Rate Risk
  - Immunization by Duration Matching
  - Dynamic Immunization