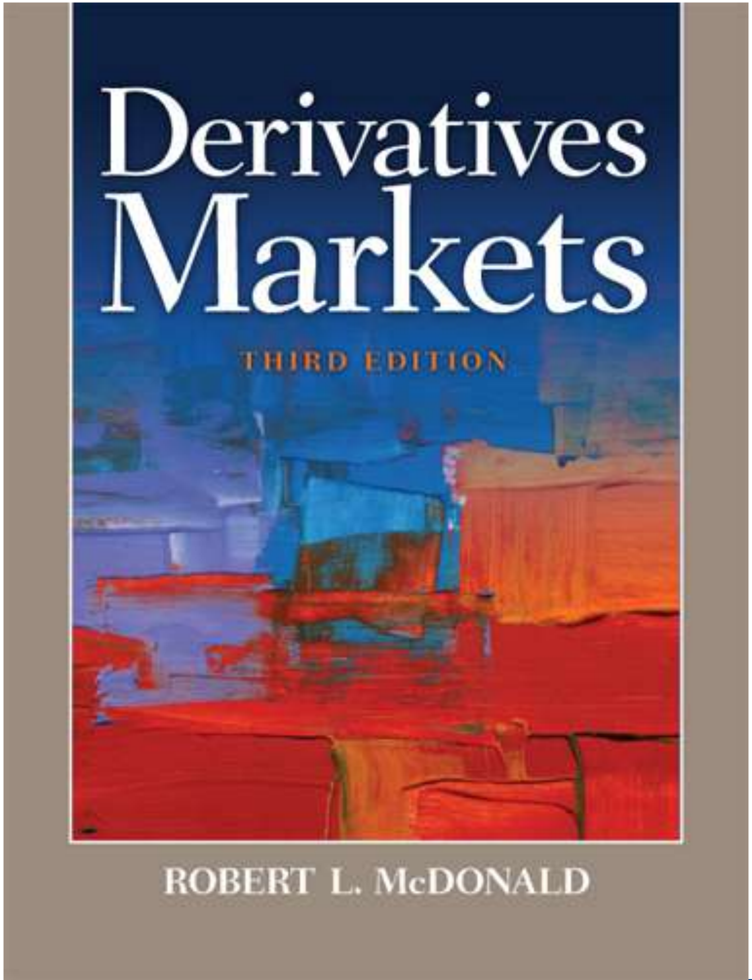


Chapter 4
(Chapter 5 in the Textbook)

Financial Forwards and Futures

Points to note

1. Alternative ways to buy a stock, see P. 4 to 5.
2. Pricing pre-paid forwards, see P. 6 to 17.
3. Pricing forwards on stock, see P. 18 to 20.
4. Creating a synthetic forward, see P. 21 to 25.
5. Synthetic forwards in market-making and arbitrage, see P. 26 – 28.
6. An interpretation of the forward pricing formula, see P. 29 – 30.
7. Future contracts, see P. 31 – 34.
8. Future contracts – marking to market, see P. 35 – 41.
9. Comparing futures and forward prices, see P. 42 – 43.
10. Quanto Index Contracts, see P. 44 – 46.

Pre-paid forward vs forward

Difference between Forward and futures

1) $F_{0,T} = FV(F_{0,T}^{P})$

$$F_{0,T}^{P} = \begin{cases} \text{a) No dividend} \\ \text{b) Discrete dividend} \\ \text{c) continuous dividend} \end{cases}$$

2) Synthetic forward $\boxed{\text{payoff} = S_T - K}$

one unit of underlying

Cash

3) Futures

1) future price at expiry

= spot price of the underlying at expiry

2) mark to market.

$$= S_0 + S_0(r-\delta)T$$

Cost of carry

Futures Contracts

- Exchange-traded "forward contracts"
- Typical features of futures contracts
  - Standardized, with specified delivery dates, locations, procedures.
  - A clearinghouse
    - Matches buy and sell orders.
    - Keeps track of members' obligations and payments.
    - After matching the trades, becomes counterparty.
- Open interest: total number of buy/sell pairs.

Futures Contracts (cont’d)

- Differences from forward contracts
  - Futures contract is settled daily. The determination of who owes what to whom is called *marking-to-market*.
  - Because of daily settlement, futures contract is liquid – it is possible to offset an obligation on a given day by entering into the opposite position.
  - Highly standardized structure → harder to customize.
  - Because of daily settlement, the nature of credit risk is different with the futures contract.
  - There are typically daily *price limits* in futures market. The price limit is a move in the futures price that triggers a temporary halt in trading.

The S&P 500 Futures Contract

- *Underlying asset:* S&P 500 stock index.
- *Notational value (the dollar value of the assets underlying one contract):*

  $250 x S&P 500 index
- *Cash-settled contract (not physical settlement)*:

On the expiration day, the S&P 500 futures contract is marked-to-market against the actual cash index. This final settlement against the cash index guarantees that the futures price equals the index value at contract expiration.

Example: S&P 500 Futures

FIGURE 5.1

Specifications for the S&P 500 index futures contract.

Underlying	S&P 500 index
Where traded	Chicago Mercantile Exchange
Size	$250 × S&P 500 index
Months	March, June, September, December
Trading ends	Business day prior to determination of settlement price
Settlement	Cash-settled, based upon opening price of S&P 500 on third Friday of expiration month

Margins and Marking to Market

- Suppose you would enter 8 long S&P 500 futures contracts with the futures price of 1,100.
- Total notional value

  = 8x$250x1100 = $2.2 million.
- A broker executes your buy order by matching with another sell order. The total number of open positions (buy/sell pairs) is called the *open interest* of the contract.

Margins and Marking to Market (cont'd)

- Both buyers and sellers need to make a deposit, which can earn interest, with the broker. The deposit is called *margin* which is intended to protect the counterparty against your failure to meet your obligations.
- Here, we suppose the margin is *10%* and *weekly settlement*.
- Margin deposit = 10% x $2.2 million

  = $220,000

Margins and Marking to Market (cont'd)

<u>*Interest rate for the margin deposit:*</u> 6% p.a. (compounded continuously).

Suppose that over the first week, the futures price drops 72.01 points to 1,027.99, our margin balance after 1 week is

P/L due to mark to market

$$\$220{,}000e^{0.06\times 1/52} + \boxed{8 \times 250 \times (1{,}027.99 - 1{,}100)}$$

$= \$76{,}233.99$

accumulated balance from week 0 to week 1

TABLE 5.8

Mark-to-market proceeds and margin balance over 10 weeks from long position in 8 S&P 500 futures contracts. The last column does not include additional margin payments. The final row represents expiration of the contract.

Week	Multiplier ($)	Futures Price	Price Change	Margin Balance($)
0	8x250= 2000.00	1100.00	—	220,000.00
1	2000.00	1027.99	–72.01	76,233.99
2	2000.00	1037.88	9.89	96,102.01
3	2000.00	1073.23	35.35	166,912.96
4	2000.00	1048.78	–24.45	118,205.66
5	2000.00	1090.32	41.54	201,422.13
6	2000.00	1106.94	16.62	234,894.67
7	2000.00	1110.98	4.04	243,245.86
8	2000.00	1024.74	–86.24	71,046.69
9	2000.00	1007.30	–17.44	36,248.72
10	2000.00	1011.65	4.35	44,990.57

Margins and Marking to Market (cont'd)

The 10-week profit on the futures position

$$\$44{,}990.57 - \$220{,}000e^{0.06\times 10/52} = -\$177{,}562.6$$

In the case of forward contract, the 10-week profit is Payoff of forward $= (S_T - K) \times 2000$

$$(1{,}011.65 - 1{,}100) \times \$2{,}000 = -\$176{,}700$$

The difference is because the interest is earned on the mark-to-market proceeds in the case of futures contract.

Margins and Marking to Market (cont'd)

- The decline in the margin balance means the broker has significantly less protection should we default. For this reason, participants are required to maintain the margin at a minimum level, called the *maintenance margin*.
- If the margin balance falls below the maintenance margin, the broker would make a *margin call*, requesting additional margin to bring the margin balance to the level of initial margin.

Margins and Marking to Market (cont'd)

- If we failed to post additional margin, the broker would close the futures position (long/short position) and return the remaining margin to the corresponding party.

Comparing Futures and Forward Prices

- *If the interest rate were not random*, then forward and future prices would be the same. (see supplementary "forwardandfutures.pdf")
- If the interest rate is random and positively (negatively) correlated with the future price, the future price will be higher (less) than the price on an otherwise identical forward contract.

Forward price $\neq$ future price

Comparing Futures and Forward Prices (cont'd)

- In general, the difference between the price of the short-lived forward and futures contract is small. However, for long-lived contracts, the difference can be significant.

Arbitrage in Practice: S&P 500 Index Arbitrage

- See P.143 to understand how the arbitrage can be achieved.

Quanto Index Contracts

Invest in Nikkei

① RMB → JPY

② JPY → Nikkei

- Contract specifications of Nikkei 225 index futures contract

Risks

① Nikkei index ② FX

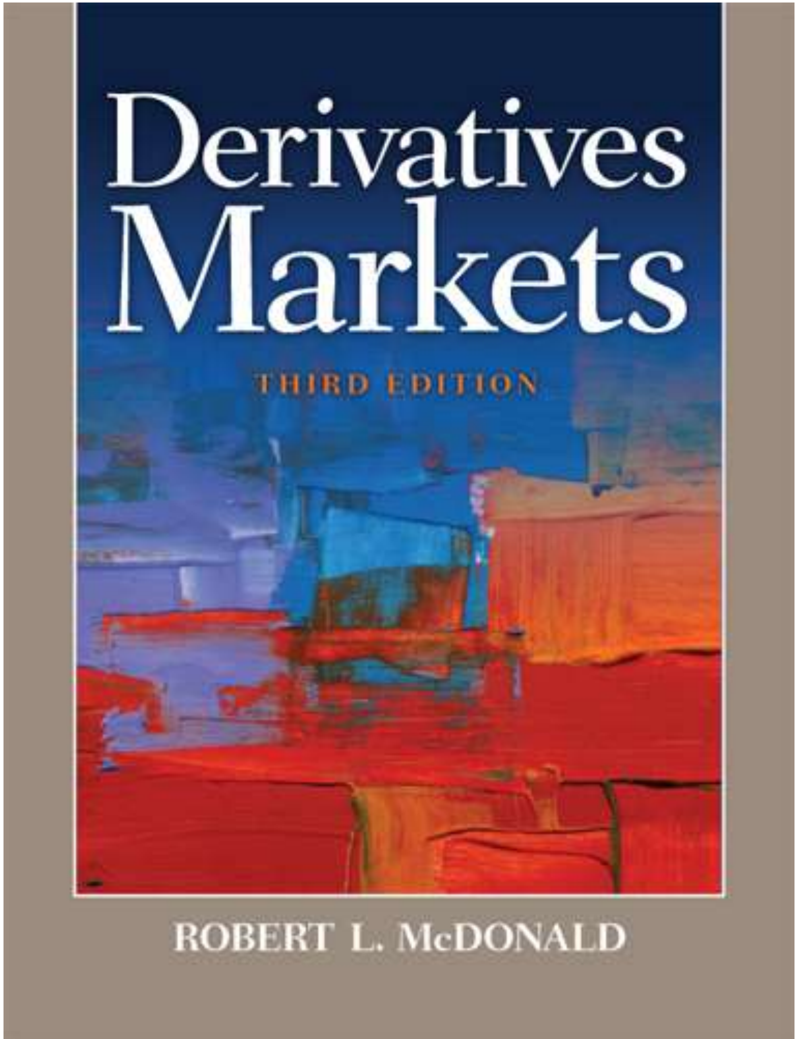
FIGURE 5.2

Specifications for the Nikkei 225 index futures contract.

Underlying	Nikkei 225 Stock Index
Where traded	Chicago Mercantile Exchange
Size	$5 × Nikkei 225 Index
Months	March, June, September, December
Trading ends	Business day prior to determination of settlement price
Settlement	Cash-settled, based upon opening Osaka quotation of the Nikkei 225 index on the second Friday of expiration month

Quanto Index Contracts (cont'd)

- The Nikkei 225 futures contact can eliminate the exchange rate risk for the US investors by using dollars to settle instead of yen.
- The contract insulates investors from currency risk, permitting them to speculate solely on whether the underlying asset rises or falls. This kind of contract is called *quanto*.



Chapter 5
(Chapter 6 in the textbook)

Commodity Forwards and Futures

Points to Note

1. What are the differences between the commodity and the financial asset? See P.3 to 5.

2. Definitions of backwardation and contango, see P.6 to 10.

3. How do the storage cost and convenience yield determine the forward price? (see $F_{0,T}$ on p.12 and 13)

   $F_{0,T} = S_0 e^{(r+u-y)T}$

4. What does the lease rate mean? See P.15.

   $\boxed{\delta_l = y - u}$

5. What is the relationship among the lease rate, storage cost and convenience yield? See P.16.

Example of commodities :

① Soybean
② corn
Arg. product

③ steel
④ crude oil
⑤ Silver
metal

⑥ pork bellies
⑦ live cattle

① Storage cost

② Convenience yield
generate profit from carrying commodities

↑ $\boxed{\text{storage cost}}$: liability of commodity carrier (holder)

↳ ↑ Futures / Forward price

↑ $\boxed{\text{Convenience yield}}$: benefit of commodity carrier (holder)

↳ ↓ Futures / Forward price

① storage cost ⟺ negative dividend

② Convenience yield ⟺ dividend

Introduction to Commodity Forwards

- Differences between commodities and financial assets include
  - *Storage costs*

    The cost of storing a physical item such as corn or copper. It can be large relative to its value.
  - *Carry markets*

    A commodity for which the forward price compensates a commodity owner for *costs of storage* is called a *carry market*. In such a market, the return on a cash-and-carry, net of all costs, is the risk-free rate.

Introduction to Commodity Forwards (cont'd)

- *Lease rate*

  A short-seller of an item may have to compensate the owner of the item for lending

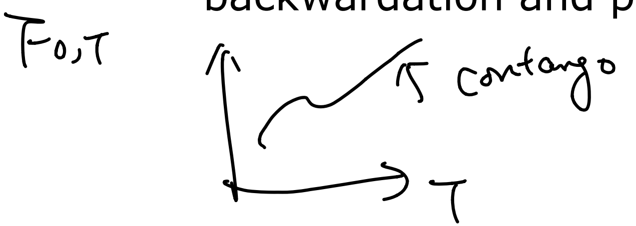
Introduction to Commodity Forwards (cont'd)

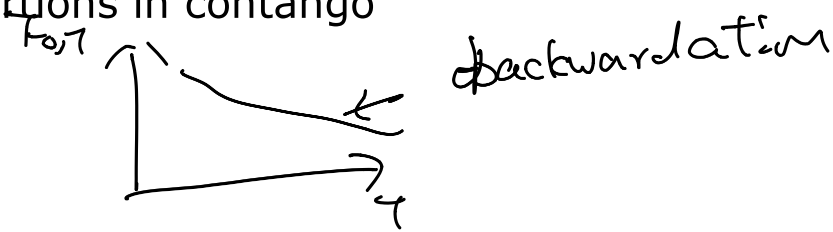
– *Convenience yield*

The owner of a commodity in a commodity-related business may receive nonmonetary benefits from physical possession of the commodity

Introduction to Commodity Forwards (cont'd)

- The set of prices for different expiration dates for a given commodity is called the **forward curve** (or the **forward strip**) for that date
- If on a given date the forward curve is upward sloping, then the market is in **contango**. If the forward curve is downward sloping, the market is in **backwardation**
  - Note that forward curves can have portions in backwardation and portions in contango





Introduction to Commodity Forwards (cont'd)

- **More Commodity Terminologies**
  - Commodities can be broadly classified as *extractive* and *renewable*.
    - **Extractive commodities** occur naturally in the ground and are obtained by mining and drilling. Examples include metals (silver, gold, and copper) and hydrocarbons, including oil and natural gas.
    - **Renewable commodities** are obtained through agriculture, and include grains (corn, soybeans), livestock (cattle, pork bellies) and lumber.

Introduction to Commodity Forwards (cont'd)

- **More Commodity Terminologies**
  - Commodities can be further classified as <u>*primary*</u> and <u>*secondary*</u>.
    - **Primary commodities** are unprocessed; corn, soybeans, oil and gold.
    - **Secondary commodities** have been processed; gasoline.

Introduction to Commodity Forwards (cont'd)

TABLE 6.1 Futures prices for various commodities, March 17, 2011.

Expiration Month	Corn (cents/bushel)	Soybeans (cents/bushel)	Gasoline (cents/gallon)	Oil (Brent) (dollars/barrel)	Gold (dollars/ounce)
April	—	—	2.9506	—	1404.20
May	646.50	1335.25	2.9563	114.90	1404.90
June	—	—	2.9491	114.65	1405.60
July	653.75	1343.50	2.9361	114.38	—
August	—	—	2.8172	114.11	1406.90
September	613.00	1321.00	2.8958	113.79	—
October	—	—	2.7775	113.49	1408.20
November	—	1302.25	2.7522	113.17	—
December	579.25	—	2.6444	112.85	1409.70

Data from CME Group.

C

back

Introduction to Commodity Forwards (cont'd)

- From Table 6.1, we have the following observations:
  - Contango: Near-term corn and soybeans, and with gold
  - Backwardation: Medium-term corn and soybeans, and with crude oil
  - Uncommon units: A barrel of oil = 42 gallons; A bushel ≈ 2,150 cubic inches; Troy ounce ≈ 1.097×1 avoirdupois ounce

The following sections are based on the materials of "Options, Futures and other Derivatives, 7 ed., by John C. Hull."

Storage Cost

Storage cost can be treated as negative income (or dividend). So,

where

$$F_{0,T} = (S_0 + U(0,T))e^{rT} \qquad U(0,T) = \sum_{i=1}^{n} PV_{0,t_i}(SC_{t_i})$$

where is $U(0,T)$ the present value of all the storage cost at 0 over the period [0, T], or

$$F_{0,T} = S_0\, e^{(r+u)T} \qquad u = -\text{ dividend yield}$$

where u is the storage cost per annum as a proportion of the spot price.

Financial asset: $F_{0,T} = \left(S_0 - \sum_{i=1}^{n} PV_{0,t_i}(D_{t_i})\right) e^{rT}$

Convenience Yield

- For consumption asset, users of this asset may feel that ownership of the physical asset provides benefits that can not be obtained by holding the futures contract. For example, oil refiner is unlikely to regard a futures contract on crude oil to be the same as crude oil held in inventory.

  So, we may have

$$F_{0,T} < (S_0 + U(0,T))e^{rT} \text{ or}$$
$$F_{0,T} < S_0\, e^{(r+u)T}$$

John Hull's book

Convenience Yield (cont'd)

- Convenience yield (y) measures the amount of benefit that is associated with physically owning an asset, rather than owning a futures contract on it. y is defined as

$$F_{0,T} = (S_0 + U(0,T))e^{(r-y)T}$$

discrete storge cost

or

$$F_{0,T} = S_0\, e^{(r+u-y)T}.$$

continuous storage cost

y reflects the market's expectations concerning the future availability. Large $y \rightarrow$ higher chance that shortages will occur.

Lease Rate = (convenience yield & storage cost)

- For a commodity owner who lends the commodity, the lease rate is like a dividend.
- With a commodity, the lease rate, δ_l, is the income earned only if the commodity is loaned. It is not directly observable, except if there is a lease market (e.g., http://www.kitco.com/commentaries/2016-05-06/Gold-Leasing-Explained.html)
- δ_l, y and u are related by

lend oil ⇒ borrower

$\uparrow$ lease rate

$$\delta_l = y - u$$

⇒ ① storage cost $\uparrow$
$\downarrow$ borrowing cost
② $\uparrow$ convenience yield

= $\uparrow$ borrow cost

$$F_{0,T} = S_0 e^{(r+u-y)T}$$

$$= S_0 e^{(r-\delta_e)T} \quad \text{where } \delta_e = y - u$$

Similar to the role of dividend yield in financial asset.

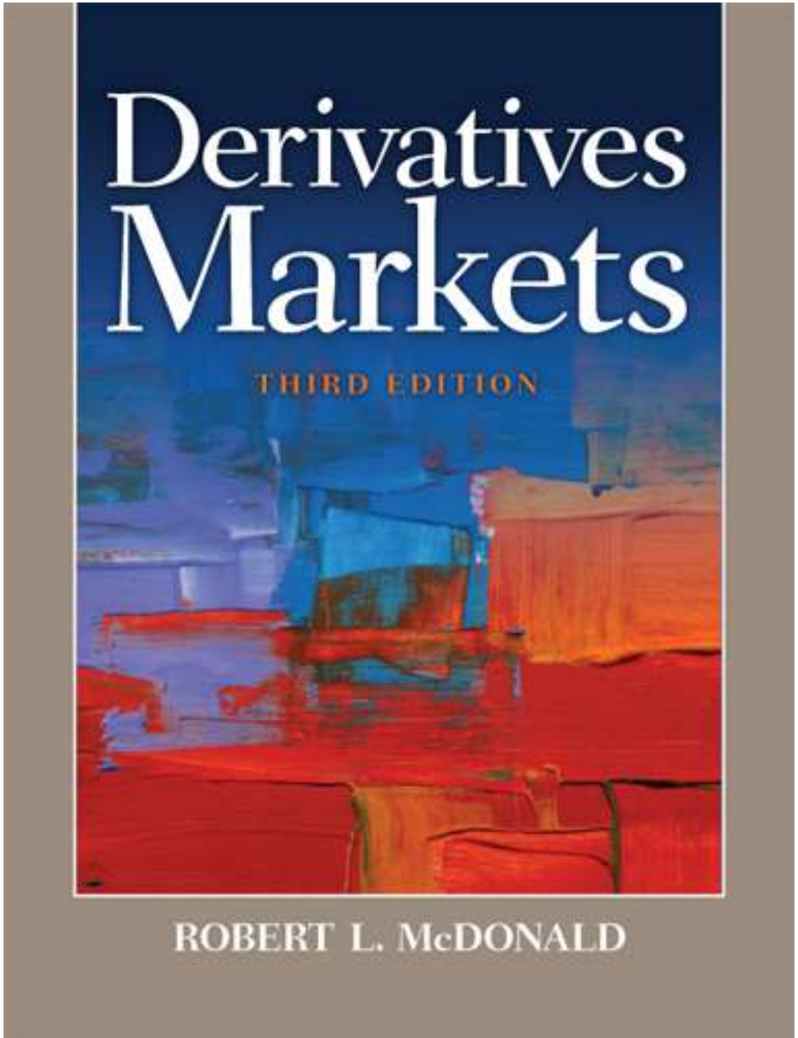
Cost of Carry

- For a commodity, the cost of carry is given by

$$\text{cost of carry} = r - q + u \;=\; r - (q - u)$$

where q is the rate of income provided by the commodity.

Net benefit for Carrying commodity



Chapter 6
(Chapter 7 in the textbook)

Bond Basics

Points to Note

1. Definition of $r_t(t_1,t_2)$, see P.4.
2. What is the relationship between the bond price $P(0, n)$ and $r(0,n)$? See P.5.

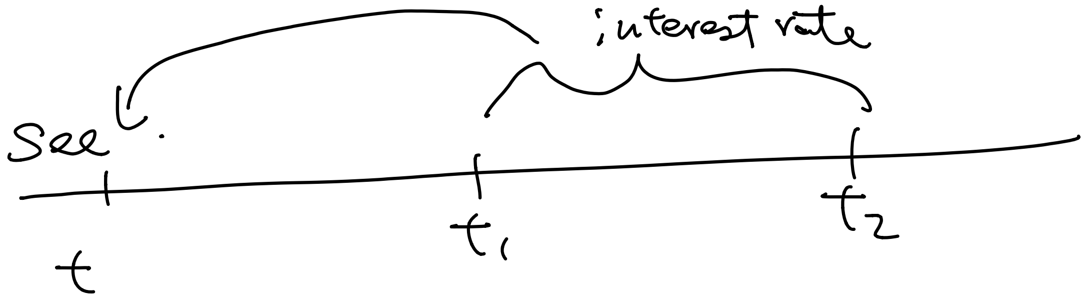
   yield to maturity
3. How to find YTM from the zero coupon price? See P.7.
4. How to find the implied forward rate? See P.8 – 9.
5. How to find the implied forward zero-coupon price? See P.10.
6. Coupon bonds, see P.12.
7. Bootstrapping zero-coupon price from coupon bonds, see P.14 – 15.
8. Definition of continuously compounded yields $r^{cc}(0, t)$.

Bond Basics

- U.S. Treasury
  - Bills (<1 year), no coupons, sell at discount
    price < Face value
  - Notes (1–10 years), Bonds (>10–30 years), with coupons
  - STRIPS (Separate Trading of Registered Interest and Principal Securities): claim to a single coupon or principal portion of a government bond, i.e., *zero-coupon bond*

Bond Basics (cont'd)

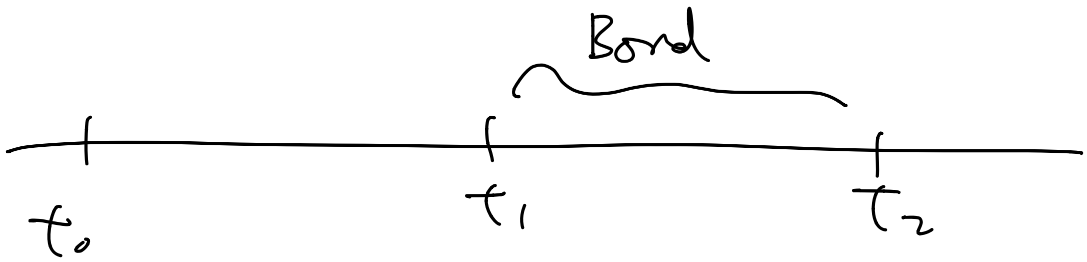
- Notation
  - $r_t\,(t_1,t_2)$: annual effective interest rate from time t_1 to t_2 prevailing at time t. If the interest rate is current –i.e., if $t = t_1$ - and if there is no risk of confusion, we will drop the subscript.
  - $P_{to}(t_1,t_2)$: price of a bond quoted at $t = t_0$ to be purchased at $t = t_1$ maturing at $t = t_2$
  - Yield to maturity: percentage increase in dollars earned from the bond



$r_t(t_1, t_2)$

$t < t_1 < t_2$

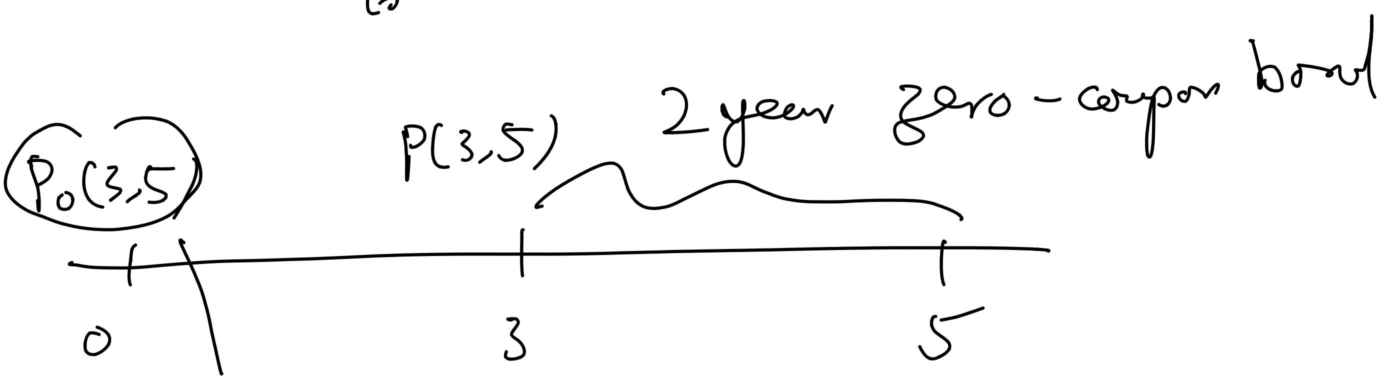
if $t = t_1$ $\quad r_{t_1}(t_1, t_2) = r(t_1, t_2)$



↑ starting time of Bond

price settling time

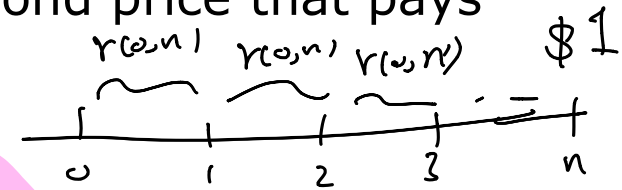
$P_{t_0}(t_1, t_2)$



Forward price of 2 yr zero-coupon bond.

Bond Basics (cont'd)

- In general, the zero-coupon bond price that pays \$1 at year n is given by



$$P(0,n)=\frac{1}{\left[1+r(0,n)\right]^{n}}$$

where $r(0, n)$ is called the annualized zero-coupon yield of the n-year zero-coupon bond.

- Zero-coupon bond price that pays C_t at year t:

$$C_t \times P(0,t)=\frac{C_t}{\left[1+r(0,t)\right]^{t}}$$

so, $P(0, t)$ is a discount factor.

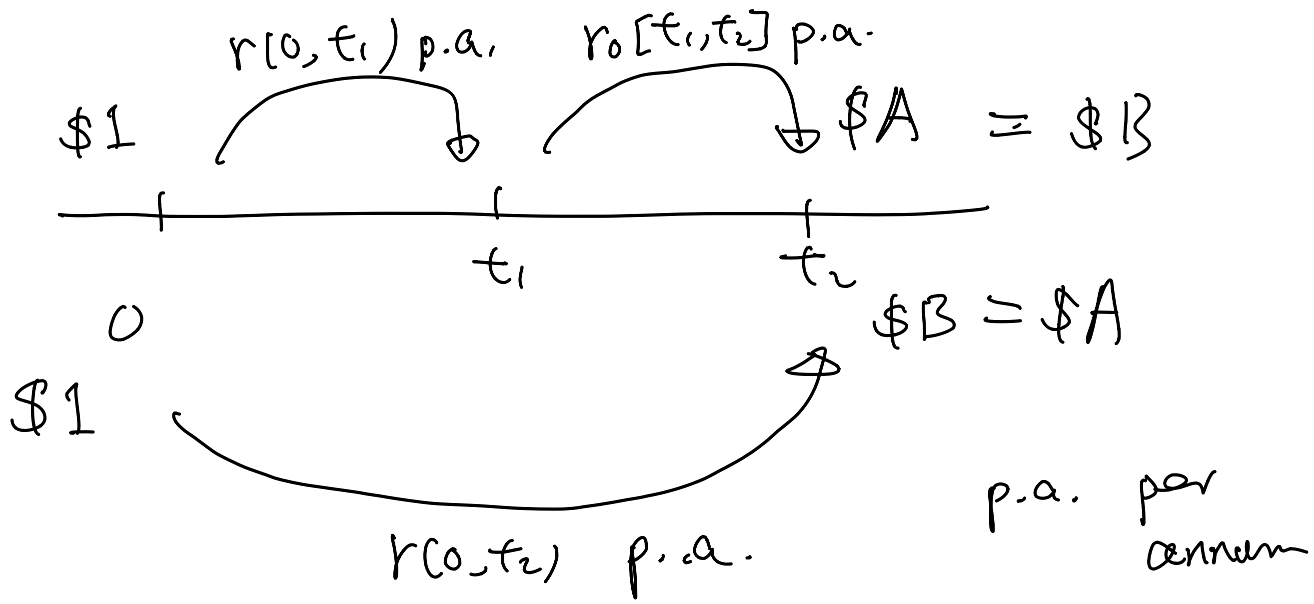
Bond Basics (cont'd)

- Zero-coupon bonds make a single payment at maturity

TABLE 7.1 Five ways to present equivalent information about default-free interest rates. All rates but those in the last column are effective annual rates.

Years to Maturity	(1) Zero-Coupon Bond Yield	(2) Zero-Coupon Bond Price	(3) ?? One-Year Implied Forward Rate	(4) Par Coupon	(5) Continuously Compounded Zero Yield
1	6.00%	0.943396 ①	6.00000%	6.00000%	5.82689%
2	6.50	0.881659 ②	7.00236	6.48423	6.29748
3	7.00	0.816298 ③	8.00705	6.95485	6.76586

① $= \dfrac{1}{(1+r(0,1))} = \dfrac{1}{1+6\%}$ ② $= \dfrac{1}{(1+6.5\%)^2}$ ③ $= \dfrac{1}{(1+7\%)^3}$



$$\$A = \$1\,(1+r(0,t_1))^{t_1}\,(1+r_0(t_1,t_2))^{t_2-t_1}$$

$$\$B = \$1\,(1+r(0,t_2))^{t_2}$$

$$\$A = \$B$$

$$\Rightarrow r_0(t_1,t_2) = \frac{(1+r(0,t_2))^{t_2}}{(1+r(0,t_1))^{t_1}} - 1$$

Implied forward rate $[t_1,t_2]$

$$= \frac{p(0,t_1)}{p(0,t_2)} - 1$$

$$r_0[0,1] = \frac{p(0,0)}{p(0,1)} - 1 = \frac{1}{p(0,1)} - 1 = \frac{1}{0.943396} - 1 = 6\%$$

	(2)	(3) ??
Years to Maturity	Zero-Coupon Bond Price	One-Year Implied Forward Rate
1	0.943396 ①	6.00000% $r_0[0,1]$
2	0.881659 ②	7.00236 $r_0[1,2]$
3	0.816298 ③	8.00705 $r_0[2,3]$

$$r_0[1,2] = \frac{P(0,1)}{P(0,2)} - 1 = 7.00236\%$$

$$r_0[2,3] = \frac{P(0,2)}{P(0,3)} - 1 = 8.00705\%$$

Bond Basics (cont'd)

- One year zero-coupon bond: $P(0,1)=0.943396$
  - Pay \$0.943396 today to receive \$1 at t=1
  - Yield to maturity (YTM) = 1/0.943396 - 1 = 6% = $r\,(0,1)$
- Two year zero-coupon bond: $P(0,2)=0.881659$
  - YTM=1/0.881659 – 1

$$=0.134225 \quad =(1+r(0,2))^2 - 1$$

$$\Rightarrow r(0,2)=0.065=6.5\%$$

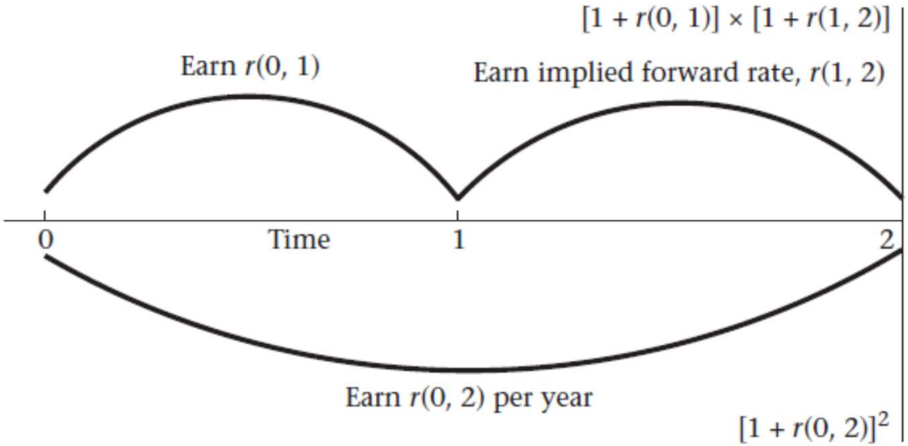
Bond Basics (cont'd)

- Yield curve: graph of annualized zero-coupon bond yields against time
- Implied forward rates
  - Implied interest rate for the future period
  - Suppose current one-year rate $r(0,1)$ and two-year rate $r(0,2)$
  - Current forward rate from year 1 to year 2, $r_0(1,2)$, must satisfy

$$[1+r_0(0,1)][1+r_0(1,2)]=[1+r_0(0,2)]^2$$

FIGURE 7.1

An investor investing for 2 years has a choice of buying a 2-year zero-coupon bond paying $[1 + r_0(0, 2)]^2$ or buying a 1-year bond paying $1 + r_0(0, 1)$ for 1 year, and reinvesting the proceeds at the implied forward rate, $r_0(1, 2)$, between years 1 and 2. The implied forward rate makes the investor indifferent between these alternatives.



Bond Basics (cont'd)

$F_{0,T} = S_0 e^{rT}$

- In general

$$[1+r_0(t_1,t_2)]^{t_2-t_1} = \frac{[1+r_0(0,t_2)]^{t_2}}{[1+r_0(0,t_1)]^{t_1}} = \frac{P(0,t_1)}{P(0,t_2)}$$

$e^{rt_1} = \frac{1}{P(0,t_1)} \cdot P(0,t_2)$

- The implied forward zero-coupon price, $P_0(t_1, t_2)$, from t_1 to t_2 is given by

Forward price of t_2-year zero coupon bond →

$$\boxed{P_0(t_1,t_2)} = \frac{1}{[1+r_0(t_1,t_2)]^{t_2-t_1}} = \frac{[1+r_0(0,t_1)]^{t_1}}{[1+r_0(0,t_2)]^{t_2}} = \frac{P(0,t_2)}{P(0,t_1)}$$

z-y

It is simply the ratio of the zero-coupon bond prices maturing at t_2 and t_1. It is actually the forward price of a t_1-year forward contract with the underlying of t_2-year zero coupon bond.

Bond Basics (cont'd)

- Example 7.1
  - What are the implied forward rate $r_0(2,3)$ and forward zero-coupon bond price $P_0(2,3)$ from year 2 to year 3? (use Table 7.1)

$$r_0(2,3) = \frac{P(0,2)}{P(0,3)} - 1 = \frac{0.881659}{0.816298} - 1 = 0.0800705$$

$$P_0(2,3) = \frac{P(0,3)}{P(0,2)} = \frac{0.816298}{0.881659} = 0.925865$$

Bond Basics (cont'd)

- Coupon bonds
  - The price at time of issue of t of a bond maturing at time T that pays n coupons of size c at time t_i where $t_i = t + i(T - t)/n$ and maturity payment of \$1

$$B_t(t,T,c,n) = \sum_{i=1}^{n} cP_t(t,t_i) + P_t(t,T)$$

  - A **par bond** has $B_t = 1$, so the **par coupon** (the coupon rate at which the bond will be priced at par) is given by

$$c = \frac{1 - P_t(t,T)}{\sum_{i=1}^{n} P_t(t,t_i)}$$

par = face value

Bond Basics (cont'd)

$$\frac{1}{(1+r(t,t_i))^i}$$

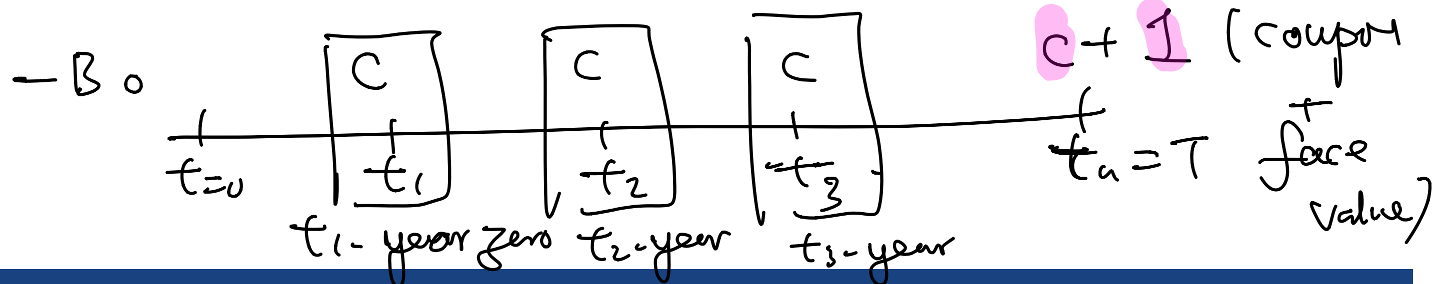
$$B_t(t,T,c,n) = \sum_{i=1}^{n} c P_t(t,t_i) + P_t(t,T)$$

- Coupon bonds (cont'd)
  - Suppose the bond makes *m* payments per year. Denoting the per-period yield to maturity as y_m, we have

$$B_t(t,T,c,n) = \sum_{i=1}^{n} \frac{c}{(1+y_m)^i} + \frac{1}{(1+y_m)^n}$$

same for all period

It is common to compute the quoted annualized yield to maturity, y, as $y = m \times y_m$.



Price at time 0 (B_0)

$B_0 = PV$ (all cash flows)

$= C P(0,t_1) + C P(0,t_2) + \dots + C P(0,t_n)$

$+ P(0,t_n)$

par bond $\quad B_0 = 1$ (face value)

$1 = C P(0,t_1) + C P(0,t_2) + \dots + (1+C) P(0,t_n)$

$$\Rightarrow \quad c = \frac{1 - P_t(t,T)}{\sum_{i=1}^{n} P_t(t,t_i)}$$

(2)	(3) ??	(4)
Zero-Coupon Bond Price	One-Year Implied Forward Rate	Par Coupon
$\boxed{0.943396}$ ①	6.00000%	6.00000% ← ① : 1-yr coupon bond
$\boxed{0.881659}$ ②	7.00236	6.48423 ← ② ← 2yr coupon bond
$\boxed{0.816298}$ ③	8.00705	6.95485 ← ③ ← 3yr coupon bond

$$① = \frac{1 - P(0,1)}{P(0,1)} = 6\%$$

$$② = \frac{1 - P(0,2)}{P(0,1) + P(0,2)} = \frac{1 - 0.881659}{0.943396 + 0.881659} = 6.48\%$$

$$③ = \frac{1 - P(0,3)}{P(0,1) + P(0,2) + P(0,3)} = 6.95\%$$

Bond Basics (cont'd)

- Zeros from Coupons
  - **Bootstrapping**: the procedure in which zero coupon bond prices are deduced from a set of coupon bond prices.
  - From Column (4) in Table 7.1, we have

$$1 = (1 + 0.06)P(0,1)$$

$$P(0,1) = 0.943396$$

The second par coupon bond gives us

$$1 = 0.0648423P(0,1) + 1.0648423P(0,2)$$

$$P(0,2) = 0.881659$$

Bond Basics (cont’d)

– Similarly, we find

$$1 = 0.0695485P(0,1) + 0.0695485P(0,2) + 1.0695485P(0,3)$$

$$P(0,3) = 0.816298$$

Bond Basics (cont'd)

- Continuously Compounded Yields
  - In general, if we have a zero-coupon bond paying \$1 at maturity, we can write its price in terms of an annualized continuously compounded yield, $r^{cc}(0,t)$, as

$$P(0,t) = e^{-r^{CC}(0,t)t}$$