Derivatives

CFA二级培训项目

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101% Contribution Breeds Professionalism

Topic Weightings in CFA Level II

Session NO.	Content	Weightings
Study Session 1-2	Quantitative Methods	5-10
Study Session 3	Economics	5-10
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Framework

Derivatives

Derivatives

- LM1 Pricing and Valuation of Forward Commitments
- LM2 Valuation of Contingent Claims

Learning Module 1

Pricing and Valuation of Forward Commitments

Framework

1. Forward
   - Principle of Arbitrage-free Pricing
   - Equity Forward and Futures Contracts
   - Interest Rate Forward and Futures Contracts(FRA)
   - Fixed-Income Forward and Futures Contracts
2. T-bond Futures
3. Swap
   - Interest Rate Swap Contracts
   - Currency Swap Contracts
   - Equity Swap Contracts

Price and Value

- The price is the predetermined price in the contract that the long should pay to the short to buy the underlying asset at the settlement date.
- **The contract value is zero** to both parties at initiation.
- **The no-arbitrage principle:** tradable securities with identical cash flow payments must have the same price. Otherwise, traders would be able to generate risk-free arbitrage profits.
  - Two assets or portfolios with identical future cash flows, regardless of future events, should have same price;
  - The portfolio should yield the risk-free rate of return, if it generates certain payoffs.

Generic Pricing: No-Arbitrage Principle

- **Pricing a forward contract** is the process of determining the **no-arbitrage** price that will make the value of the contract be zero to both sides at the initiation of the contract.
  - Forward price=price that would not permit profitable riskless arbitrage in frictionless markets
  - $FP=S_0 \times (1+r_f)^T$ + Carrying Costs - Carrying Benefits
- **Strategies if there exists arbitrage profits**
  - Cash-and-Carry Arbitrage
  - Reverse Cash-and-Carry Arbitrage

Forwards Arbitrage

➢ **<u>Cash-and-Carry Arbitrage</u>** with forward contract market price **<u>too high</u>** relative to carry arbitrage model.

- If $FP > S_0 \times (1+R_f)^T$

At initiation	At settlement date
• Short a forward contract • Borrow S_0 at the risk-free rate • Use the money to buy the underlying bond	• Deliver the underlying to the long • Get FP from the long • Repay the loan amount of $S_0 \times (1+R_f)^T$

Forwards Arbitrage

➢ **Reverse Cash-and-Carry Arbitrage** with forward contract market price **too low** relative to carry arbitrage model.

- If $FP < S_0 \times (1+R_f)^T$

At initiation	At settlement date
• Long a forward contract • Short sell the underlying bond to get S_0 • Invest S_0 at the risk-free rate	• Pay the short FP to get the underlying bond • Close out the short position by delivering the bond • Receive investment proceeds $S_0 \times (1+R_f)^T$

Valuation of a forward contract

- **Valuation of a forward contract** means determining the value of the contract at some time during the life of the contract.
- **Two strategies** to value a forward contract
  - Enter into an opposite contract and calculate the P/L at the moment
    - ✓ Same tenor
    - ✓ Same underling
    - ✓ Same counterparty to avoid counterparty risk
    - ✓ Is appropriate if suitable opposite contracts trading actively in the market

$$V_{long} = PV_{t,T}\left[F_t(T) - F_0(T)\right] = \frac{F_t(T) - F_0(T)}{\left(1+R_f\right)^{T-t}}$$

  - Discounting back all the possible cash flow in the future
    - ✓ Do not forget benefits and costs
    - ✓ Use appropriate discounting rates

$$V_{long} = S_t - PVD_t - \frac{FP}{(1+R_f)^{T-t}}$$

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Pricing and Valuation of a forward contract

- **Formula**

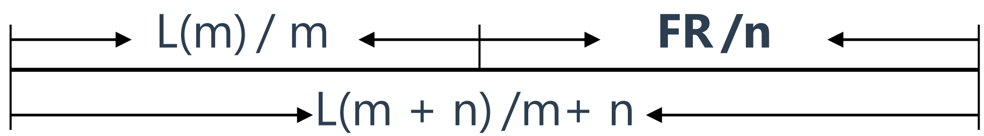
Contract	T=0→Price	T=t→Value
T-bill Forwards	$FP = S_0 \times (1+R_f)^T$	$V_{long} = S_t - \frac{FP}{(1+R_f)^{T-t}}$
Forward on Dividend-Paying Stock	$FP = (S_0 - PVD_0) \times (1+R_f)^T$	$V_{long} = S_t - PVD_t - \frac{FP}{(1+R_f)^{T-t}}$
Forward on an Equity Index	$R_f^c = In(1+R_f)$ $FP = S_0 \times e^{(R_f^c - \delta^c)\times T}$	$V_{long} = \frac{S_t}{e^{\delta^e \times (T-t)}} - \frac{FP}{e^{R_f^c \times (T-t)}}$
Coupon Bonds	$FP = (S_0 - PVC_0) \times (1+R_f)^T$	$V_{long} = (S_t - PVC_t) - \frac{FP}{(1+R_f)^{T-t}}$

Forward Rate Agreements (FRAs)

- **A Forward Rate Agreement (FRA) is a forward contract on an interest rate (LIBOR).**
  - The long position can be viewed as the right and the obligation to borrow at the forward rate in the future;
  - The short position can be viewed as the right and the obligation to lend at the forward rate in the future;
  - No loan is actually made, and FRAs are always settled in cash at contract expiration.
- **Let's take a 1×4 FRA for example. A 1×4 FRA is**
  - a forward contract expires in 1 month,
  - and the underlying loan is settled in 4 months,
  - with a 3-month notional loan period.
  - The underlying interest rate is 90-day LIBOR in 30 days from now.

FRA Pricing

- **The forward price in an FRA is the no-arbitrage forward rate (FR)**
  - If spot rates are known, The FR is just the unbiased estimate of the forward interest rate:



$$(1 + L_m \times m / 360)\ (1 + FR \times n / 360) = (1 + L_{m+n} \times (m+n) / 360)$$

Forward Pricing and Valuation – FRA

➢ LIBOR, Euribor, and FRAs (Con't)

Settlement: settle in cash, but no actual loan is made at the settlement date.

- **Payoff qualitative analysis:**
  - ✓ If the reference rate at the expiration date is above the specified contract rate, the long will receive cash payment from the short;
  - ✓ If the reference rate at the expiration date is below the contract rate, the short will receive cash payment from the long.
- **Payoff quantitative analysis**

$$\boxed{(\text{Notional principal})\left[\frac{(\text{Floating rate at settlement-forward rate})\left[\frac{\text{days}}{360}\right]}{1+\text{Floating rate at settlement}\left[\frac{\text{days}}{360}\right]}\right]}$$

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T-bond Futures Contracts

- Underlying: Hypothetical 30 year treasury bond with 6% coupon rate.
- Bond can be deliverable: $100,000 par value T-bonds with any coupon but with a maturity of at least 15 years.
- The short has a delivery option to choose which bond to deliver. Each bond is given a **conversion factor (CF),** which means a specific bond is equivalent to CF standard bond underlying in futures contract.
  - For a specific Bond A:

$$FP_{标准} = FP_A \times \frac{1}{CF_A}$$

- The short designates which bond he will deliver (**cheapest-to-deliver** bond).

Arbitrage from T-Bond futures

- **There are methods to buy the underlying bond A**
  - Buy bond A through T-bond futures

$$V_1 = FP_{标准} \times CF_A + AI_T$$

  - Buy bond through holding the bond at the beginning of the period

$$V_2 = (S_0^{clean} + AI_0) \times (1 + R_f)^T - FVC$$

- **<u>The available arbitrage profit</u> is the present value of this difference**

$$Arbitrage\ profit = PV\left|V_2 - V_1\right|$$

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Quoted futures price and forward price

- **Bond price is usually quoted as clean price**
  - Clean price=full price-accrued interest
  - First, the futures price can be written as

$$FP^{full} = (S_0^{full} - PVC_0) \times (1+R_f)^T = S_0 \times (1+R_f)^T - FVC$$

  - If S_0 is given by clean price(quoted price)

$$FP^{full} = (S_0^{clean} + AI_0) \times (1+R_f)^T - FVC$$

  - If the futures price is quoted as clean price

$$FP^{clean} + AI_T = (S_0^{clean} + AI_0) \times (1+R_f)^T - FVC$$

  - Noted that $AI_T \neq AI_0 * (1+R_f)^T$

- **The quoted futures price is adjusted with conversion factor**

$$QFP^{clean} = FP^{clean} \times \frac{1}{CF} = \left[\left(S_0^{clean} + AI_0 \right) \times (1+R_f)^T - AI_T - FVC \right] \times \frac{1}{CF}$$

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Pricing a plain vanilla swap

- Since a floating-rate bond has a value equal to its par value at initiation, what we will do is to find a fixed-rate bond with a value equal to the same par value at initiation. Denote C as the fixed coupon amount when the par value is equal to 1(also known as fixed swap rate), we have:
  - $1 = C \times B_1 + C \times B_2 + C \times B_3 + \ldots\ldots + C \times B_n + 1 \times B_n$

$$C = \frac{1 - B_n}{B_1 + B_2 + \cdots + B_n}$$

  - Recall that B_n is the discount factor, which is the present value of \$1 in n periods. **It's important to note that C is a periodic rate, and you must annualize it to get the annual swap rate.**
  - Swap rate=annualized periodic rate(C)

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Valuing a plain vanilla swap

- The value of a receive-fixed, pay-floating interest rate swap is simply the value of buying a fixed-rate bond and issuing a floating-rate bond.

Paying fixed rate

Company X $\longrightarrow$ Company Y

Company X $\longleftarrow$ Company Y

Paying floating rate

  - Notes: the value of a floating rate bond will be equal to the notional amount at any of its periodic settlement dates when the next payment is set to the market rate (floating).

- The valuation formula:

$$V_{swap}(X) = B_{flt} - B_{fix} \quad V_{swap}(Y) = B_{fix} - B_{flt}$$

$$Or \quad V_{payer\ swap} = PV_{t,T}[F_t(swap\ rate) - F_0(swap\ rate)]$$

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Pricing a currency swap

- **Currency Swap**
  - A currency swap entails the exchange of principal and interest in one currency for the principal and interest in another currency.
  - Principal is exchanged at beginning/inception and end/maturity.
- **There are four ways to construct the swap**
  - Swap 1: pay dollar fixed at 5.56% and receive Euro fixed at 3.68%.
  - Swap 2: pay dollar fixed at 5.56% and receive Euro floating.
  - Swap 3: pay dollar floating and receive Euro fixed at 3.68%.
  - Swap 4: pay dollar floating and receive Euro floating.
    - ✓ In the swap 4 (floating for floating), there **is no pricing problem** because there is no fixed rate. We should only set the notional principal to €0.8 for every 1$.

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Valuation a currency swap

Currency Swap

- Some days later, the term structures in both countries **will change**, and the exchange rate will also be different. You can calculate the fixed- and floating-rate bond prices in both currencies, and then you will get the swap value just as you do in a plain vanilla swap.
- The valuation of currency swap is given by:

$$\boxed{\begin{aligned} V_{Swap} &= B_D - S_0 B_F \\ V_{swap} &= S_0 B_F - B_D \end{aligned}}$$

Pricing an equity swap

- There are three types of equity swaps: (1) pay fixed rate and receive equity return; (2) pay floating rate and receive equity return; (3) pay one equity return and receive another equity return. We only need to price the first type of swaps because there are no fixed rates in the other two.
- We have the same formula as for the plain vanilla swap to get the periodic swap rate of an equity swap:

$$C = \frac{1 - B_n}{B_1 + B_2 + \cdots + B_n}$$

- Why is this the case? We can exchange a fixed-rate bond with periodic coupon rate of C for a stock or an index with the notional amount equal to the par value of the bond, because the bond value at inception is equal to par.

Learning Module 2

Valuation of Contingent Claims

Framework

1. Binomial Model——The Expectations Approach
   - The one –period binomial stock model
   - The two –period binomial stock model
   - Interest rate binomial model
2. Black-Scholes-Merton Model
3. Option Greeks and Implied Volatility
4. Binomial Model——The No-arbitrage Approach
5. Black Option Valuation Model
   - Option On Futures
   - Interest Rate Option
   - Swaptions

Create synthetic instruments

- **There are two reasons why investors might wants to create synthetic positions in the securities.**
  - **To price options** by using combinations of the other instruments with known prices.
  - **To earn arbitrage profits** by exploiting relative mispricing among the four securities. If put-call parity doesn't hold, an arbitrage profit is available.

Create synthetic instruments

- **There are four synthetic instruments**
  - A synthetic European call option: $$C_0 = P_0 + S_0 - \frac{X}{(1+R_f)^T}$$

    synthetic call = put + stock – bond

  - A synthetic European put option: $$P_0 = C_0 + \frac{X}{(1+R_f)^T} - S_0$$

    synthetic put = call + bond – stock

  - A synthetic pure-discount risk-less bond: $$\frac{X}{(1+R_f)^T} = P_0 + S_0 - C_0$$

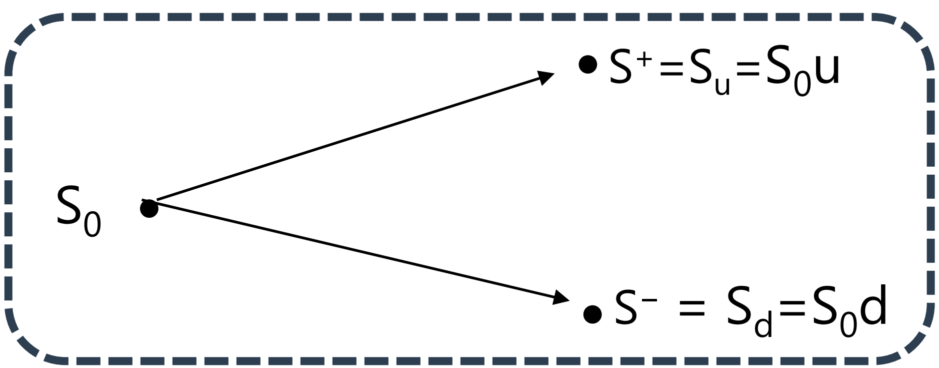
    synthetic bond = put + stock – call

  - A synthetic stock position: $$S_0 = C_0 + \frac{X}{(1+R_f)^T} - P_0$$

    synthetic stock = call + bond – put

One-period binomial model

- **A binomial model:** A model for pricing options in which the underlying price can move to only one of two possible new prices.
  - At time 0 node, there are only two possible future paths in the binomial process, an up move (S^+) and a down move (S^-).
- We start off by having only one binomial period, which means that the underlying price moves to two new prices at option expiration.
  - Assume that u = 1/d.



Expectation approach

- Risk-neutral probability of an up move is π_u; Risk-neutral probability of an down move is $\pi_d = 1 - \pi_u$

$$\pi_u = \frac{1 + R_f - d}{u - d}$$

- We start with a call option. If the stock goes up to S_1^+, the call option will be worth C_1^+. If the stock goes down to S_1^-, the call option will be worth C_1^-. We know that the value of a call option will be its intrinsic value on expiration date. Thus we get: $C_1^+ = \text{Max}(0, S_1^+ - X)$; $C_1^- = \text{Max}(0, S_1^- - X)$

$$\text{value of an option: c} = \left[\pi_u C_1^+ + \pi_d C_1^-\right] \times \frac{1}{(1+R_f)^T}$$

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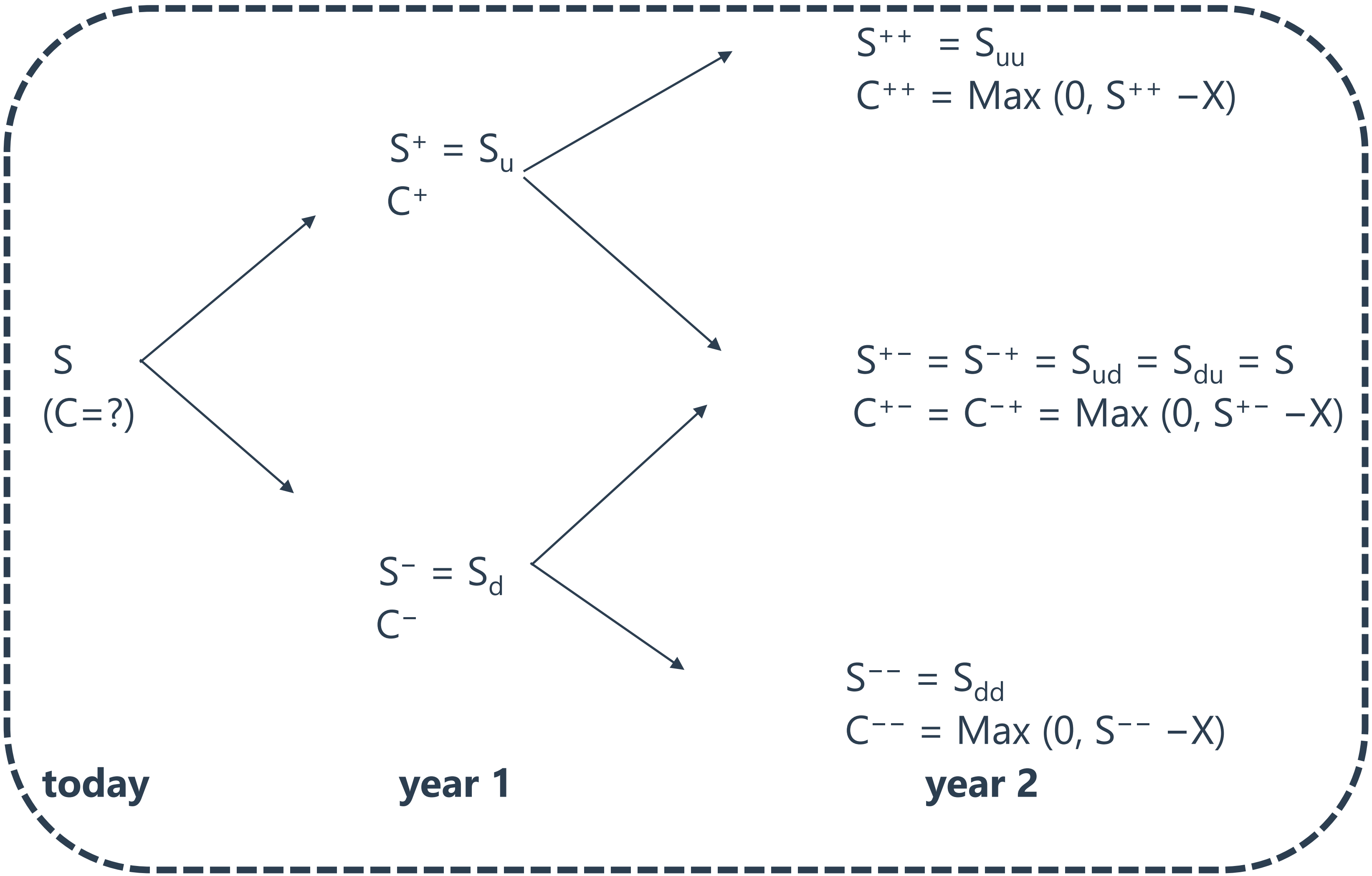
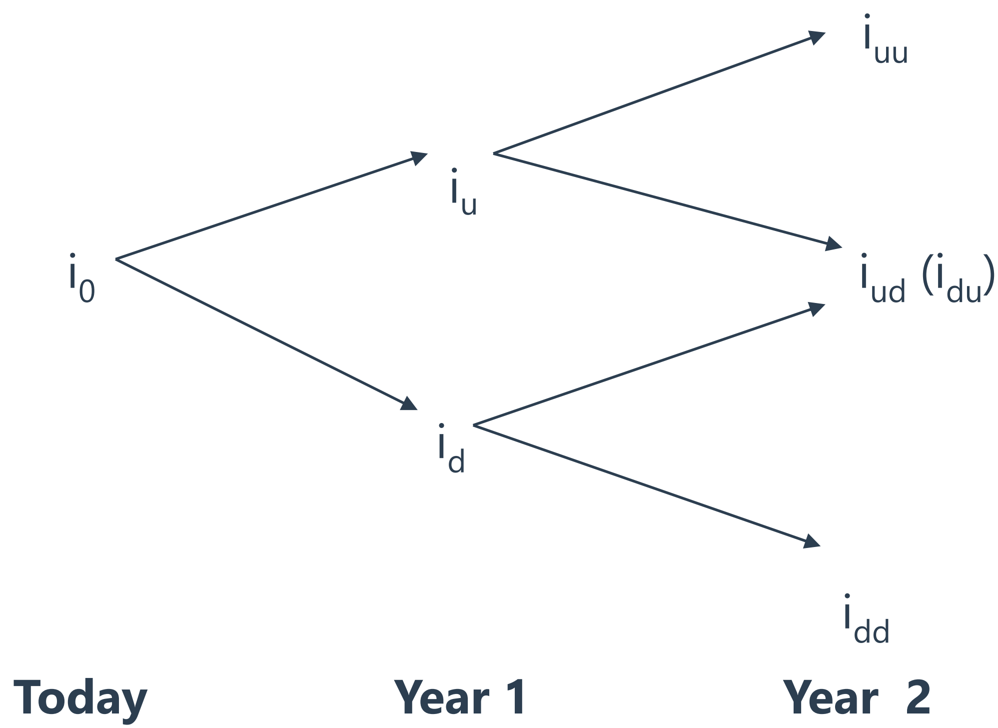
The two –period binomial model



The binomial interest rate tree

- The **binomial interest rate tree** is a set of possible interest rate paths that we use to value options on bonds or interest rates.
- **Two-Period Binomial Interest Rate Tree**



The binomial interest rate tree

- You don't need to know how to construct an interest rate tree, since it will be given to you on the exam, we will learn that from Fixed Income.
- You should know that the interest rates given **are <u>one-year forward rates from each node</u>.**
- You also should know that **<u>risk-neutral probabilities</u>** for The binomial interest rate tree , π and $1-\pi$, are always 0.5.

Interest rate option

- **Interest rate call option**
  - An option which has a positive payoff if the reference interest rate, usually the market interest rate, is greater than the exercise rate.
  - Payoff=max{0, reference rate-exercise rate}*notional principal
- **Interest rate put option**
  - An option which has a positive payoff if the reference interest rate, usually the market interest rate, is smaller than the exercise rate.
  - Payoff=max{0, exercise rate-reference rate}*notional principal

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Continuous-time option pricing model

- The **underlying assumptions** of the BSM model are
  - The price of the underlying asset follows a lognormal distribution;
  - The (continuous) risk-free rate is known and constant;
  - The volatility of the underlying asset is known and constant;
  - The markets are frictionless;
  - There are no cash flows on the underlying asset;
  - The options valued are European options.

The Value of European option using the BSM

- **The BSM formulas for the prices of European call and put options are:**

$$C_0 = [S_0 \times N(d_1)] - [X \times e^{-R_f^c \times T} \times N(d_2)]$$

$$P_0 = C_0 - S_0 + \left(X \times e^{-R_f^c \times T}\right)$$

Remember that you can always use put-call parity to calculate the put value

- **where:**
  - S_0 = underlying asset price; X = strike price; T = time to maturity
  - R_f^c = continuously compounded risk-free rate
  - σ = volatility of the underlying asset
  - N( ) = cumulative normal probability

$$d_1 = \frac{\ln\left(\frac{S_0}{X}\right) + \left[R_f^c + (0.5 \times \sigma^2)\right] \times T}{\sigma \times \sqrt{T}}$$

$$d_2 = d_1 - (\sigma \times \sqrt{T})$$

Features of BSM

- **Leveraged stock investment**
  - Borrow money to invest in stock

$$C_0 = S_0 \times N(d_1) - X \times e^{-R_f^c \times T} \times N(d_2)$$

  - Buying the bond(or lend) with the proceeds from short selling the underlying

$$P_0 = X \times e^{-R_f^c \times T} \times N(-d_2) - S_0 \times N(-d_1)$$

- **$N(d_2)$:** The prob. of an in-the-money call
- **The present value of option payoff**

$$C_0 = e^{-R_f^c \times T}\left\{[S_0 e^{R_f^c \times T} \times N(d_1)] - [X \times N(d_2)]\right\}$$

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Option Greeks

Greeks	Sensitivity factor	Relationship	
		Call option	Put option
Delta	Underlying price	Positive (Delta>0)	Negative (Delta<0)
Vega	Volatility	Positive (Vega>0)	Positive (Vega>0)
Rho	Risk-free rate	Positive (Rho>0)	Negative (Rho<0)
Theta	Passage of time	Closer to maturity → value declines (Theta<0)	Closer to maturity → value declines (Theta<0*)
/	Strike price	Negative	Positive

- The features of Theta is also called **time decay**. There is an exception when the European put option is deep in the money, the residual time to maturity has not worthy to long position.

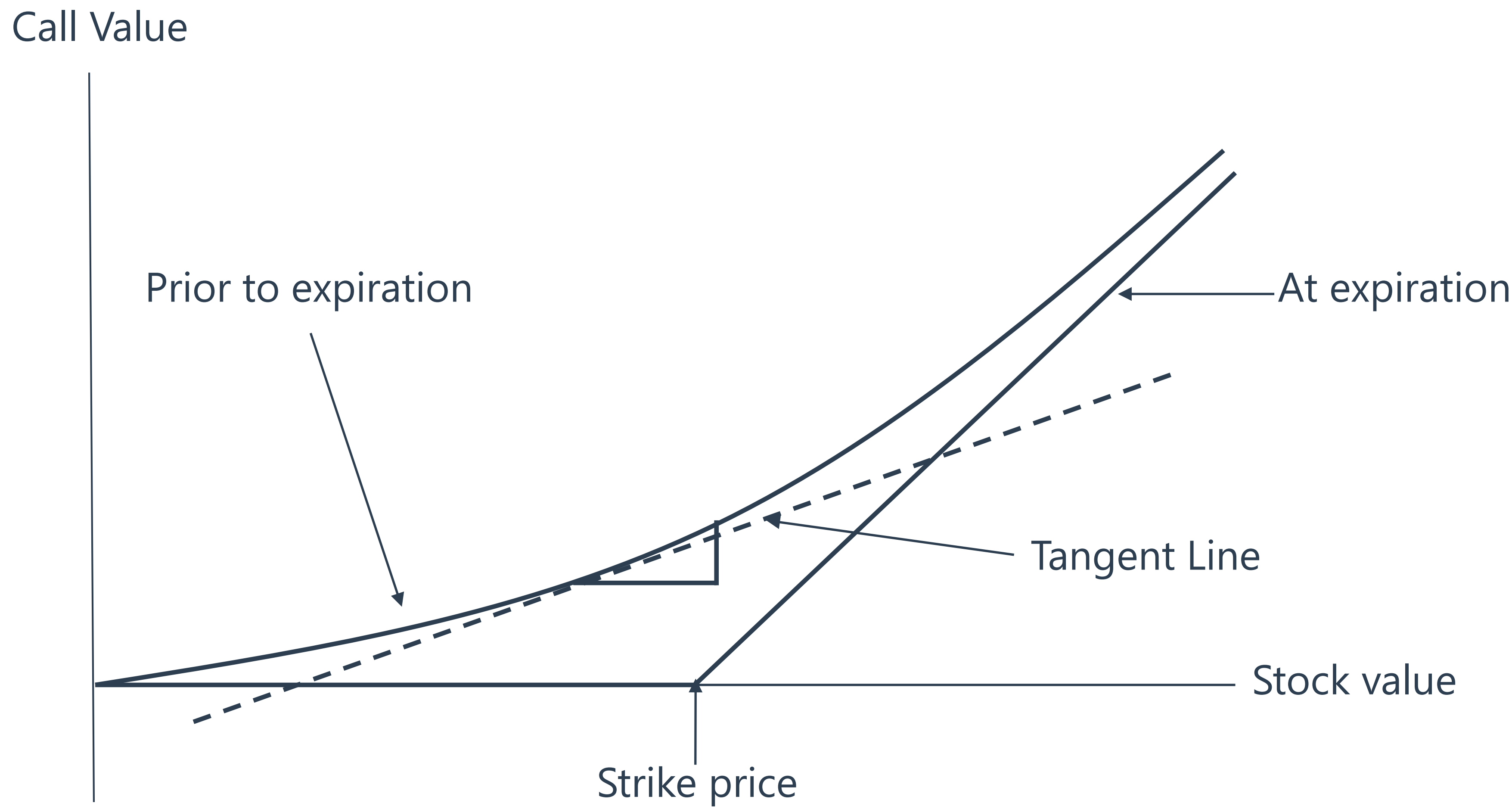
The Option Delta

- The relationship between the option price and the price of the underlying asset has a special name: the delta. The option delta is defined as:
  - delta = Change in option price / Change in underlying price
- The relationship between delta of a call and put:
  - The call option's delta is defined as:
    - ✓ $delta_{call} = (C_1 - C_0)/(S_1 - S_0) = \Delta C/\Delta S$
  - The delta of a put option is the call option's **delta minus one**:
    - ✓ $delta_{put} = (P_1 - P_0)/(S_1 - S_0) = \Delta P/\Delta S = delta_{call} - 1$
- The BSM perspective:
  - The call option's delta is also equal to $N(d_1)$ from the BSM model, and the put option's delta equals $N(d_1) - 1$.
  - If the underlying has a dividend yield of δ, the call option's delta is also equal to $e^{-\delta T}N(d_1)$ from the BSM model, and the put option's delta equals $e^{-\delta T}(N(d_1) - 1)$.

The Option Delta

- **The call delta increases from 0 to 1 as stock price increases.**
  - When the call option is deep out-of-the-money, the call delta is close to zero. The option price changes a very small amount for a given change in the stock price.
  - When the call option is deep in-the-money, the call delta is close to one. The option price changes almost one dollar for a one-dollar change in the stock price.
- **The put delta increases from -1 to 0 as stock price increases.**
  - When the put option is deep in-the-money, the put delta is close to -1.
  - When the put option is deep out-of-the-money, the put delta is close to zero.
- **When t approaches maturity, a in-the-money call's delta is close to 1,while a out-of-the-money call's delta is close to 0.**

The Option Delta



Dynamic hedging

- However, the delta-neutral hedging is a **dynamic process**, since **the delta is constantly changing**.
  - The delta will change if the underlying stock price changes.
  - The delta would change as the option moves toward the expiration day.
  - As the delta changes, the number of calls that should **be sold or bought** to construct the delta-neutral portfolio changes.
  - Delta-neutral hedging is often referred to as dynamic hedging.

$$number\ of\ options\ needed\ to\ delta\ hedge = \frac{number\ of\ shares\ hedged}{delta\ of\ call\ option}$$

$$= number\ of\ shares\ hedged \times hedge\ ratio$$

The Option Gamma

- **The gamma defines** the sensitivity of the option delta to a change in the price of the underlying asset. The option gamma is defined as:
  - gamma = $(delta_1 - delta_0)/(S_1 - S_0) = \Delta delta/\Delta S$
- **Call and put options on the same stock with the same T and X have equal gammas.**
  - A long position in calls or puts will have a positive gamma.
  - Gamma is largest when the option is at-the-money.
  - If the option is deep in- or out-of-the-money, gamma approaches zero.
- **Gamma is largest when the option is at the money**, which means delta is very sensitive to a change in the stock price. Then we must rebalance the delta-neutral portfolio more frequently. This leads to higher transaction cost .

The critical role of volatility

- **Historical volatility and implied volatility**
  - Historical volatility is using historical data to calculate the variance and standard deviation of the continuously compounded returns.

$$S^2_{R_i^c} = \frac{\sum_{i=1}^{N}\left(R_i^c - \overline{R}_i^c\right)^2}{N-1}$$

$$\sigma = \sqrt{S^2_{R_i^c}}$$

  - If we have S_0, X, R_f , and T, we can set the BSM price equal to the market price and then work backwards to get the volatility. This volatility is called the **implied volatility**. The most basic method to get the implied volatility is trial and error.

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No-arbitrage approach with binomial tree

- **Hedge Ratio:**

$$h\left(\text{hedge ratio}\right)=\frac{C_1^+ - C_1^-}{S_1^+ - S_1^-}(\text{shares per option})$$

- If the portfolio is constructed as long 1 call and short h stock, the portfolio should exist no delta risk.
  - $c_0 = hS_0 + PV(-hS^- + c^-) = hS_0 + PV(-hS^+ + c^+)$ where $h \geq 0$
  - $p_0 = hS_0 + PV(-hS^- + p^-) = hS_0 + PV(-hS^+ + p^+)$ where $h \leq 0$

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Black Model

- **Options on Futures**
  - Option Underlying: futures price
  - Call option is the present value of the difference between part of futures price and part of exercise price;
  - Leverage: Call option can be thought as long futures financed by bond.
- **Interest rate Option**
  - Option Underlying: Forward rate or FRA rate;
  - Interest rate call option gains when rates rise and put option gains when rate fall.
- **Option on Swap**
  - Option Underlying: Forward swap rate
  - Gives the holder the right, but not the obligation, to enter a swap at the pre-agreed swap rate—the exercise rate.

Swaption contracts

- A ***swaption*** is an option to enter into a swap. We will focus on the plain vanilla interest rate swaption. The notation for swaptions is similar to FRAs. For example, a swaption that matures in 2 years and gives the holder the right to enter into a 3-year swap at the end of the second year is a 2×5 swaption.
- A ***payer swaption*** is an option to enter into a swap as the ***fixed-rate payer***.
  - If interest rate increases, the payer swaption value will go up. So a payer swaption is equivalent to a put option on a coupon bond. *Another view?*
  - *It's also equivalent to a **call option on floating rate**.* 从利率上涨中获利
- A ***receiver swaption*** is an option to enter into a swap as the ***fixed-rate receiver*** (the floating-rate payer). If interest rate increases, the receiver swaption value will go down. So a receiver swaption is equivalent to **a call option on a coupon bond**. 从利率下跌中获利

It’s not the end but just beginning.

Thought is already is late, exactly is the earliest time.

感到晚了的时候其实是最早的时候。

问题反馈

- 如果您认为金程**课程讲义/题库/视频**或其他资料中**存在错误，欢迎您告诉我们**，所有提交的内容我们会在最快时间内核查并给与答复。
- **如何告诉我们?**
  - 将您发现的问题通过电子邮件告知我们，具体的内容包含：
    - ✓ 您的姓名或网校账号
    - ✓ 所在班级（E.g.,2023年5月CFA二级智能班）
    - ✓ 问题所在科目（若未知科目，请提供章节、知识点）和页码
    - ✓ 您对问题的详细描述和您的见解
  - 请发送电子邮件至：academic.support@gfedu.net
- **非常感谢您对金程教育的支持，您的每一次反馈都是我们成长的动力。**后续我们也将开通其他问题反馈渠道（如微信等）。