Chapter Objectives:

This chapter serves to introduce the student to the institutional framework within which exchange rates are determined. This chapter lays the foundation for much of the discussion throughout the remainder of the text, thus it deserves your careful attention.

Chapter Outline

- Function and Structure of the FX Market
- The Spot Market
- The Forward Market

The Function and Structure of the FX Market

- FX Market Participants
- Correspondent Banking Relationships

FX Market Participants

- The FX market is a two-tiered market:
  - Interbank Market (Wholesale)
    - About 700 banks worldwide stand ready to make a market in foreign exchange.
    - Nonbank dealers account for about 20% of the market.
    - There are FX brokers who match buy and sell orders but do not carry inventory and FX specialists.
  - Client Market (Retail)
    - Market participants include international banks, their customers, nonbank dealers, FX brokers, and central banks.

Circadian Rhythms of the FX Market

- Electronic Conversations per Hour
  - Tokyo, London, New York, others

Graph showing the electronic conversations per hour across different time zones.
Correspondent Banking Relationships

- Large commercial banks maintain demand deposit accounts with one another which facilitates the efficient functioning of the FX market.

Bank A
London

Bank B
NYC

\[ \text{£}200 \xrightarrow{} \text{£}100 \xrightarrow{} \text{S}\$200 \xrightarrow{} \text{£}200 \]

Correspondent Banking Relationships

- Bank A is in London, Bank B is in New York.
- The current exchange rate is £1.00 = $2.00.
- A currency trader employed at Bank A buys £100m from a currency trader at Bank B for $200m settled using its correspondent relationship.

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
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<tbody>
<tr>
<td>£ deposit at B</td>
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<tr>
<td>B’s Deposit</td>
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<td>Other L&amp;E</td>
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<td>Total Assets</td>
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<tr>
<td>Total L&amp;E</td>
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</table>

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Total L&amp;E</td>
<td>£2,200m</td>
</tr>
</tbody>
</table>

Correspondent Banking Relationships

- International commercial banks communicate with one another with:
  - CHIPS: Clearing House Interbank Payments System
  - ECHO Exchange Clearing House Limited, the first global clearinghouse for settling interbank FX transactions.

The Spot Market

- Spot Rate Quotations
- The Bid-Ask Spread
- Spot FX trading
- Cross Rates

Spot Rate Quotations

- Direct quotation
  - the U.S. dollar equivalent
  - e.g. “a Japanese Yen is worth about a penny”
- Indirect Quotation
  - the price of a U.S. dollar in the foreign currency
  - e.g. “you get 100 yen to the dollar”
- See the insert card from your textbook.
## Spot Rate Quotations

<table>
<thead>
<tr>
<th>Currency</th>
<th>USD per Currency Thursday</th>
<th>USD per Currency Friday</th>
<th>Currency per USD Thursday</th>
<th>Currency per USD Friday</th>
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<tr>
<td>Argentina (Peso)</td>
<td>0.0398</td>
<td>0.0392</td>
<td>8.1315</td>
<td>8.1757</td>
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<td>1.1959</td>
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<td>0.8215</td>
</tr>
<tr>
<td>Canada (Dollar)</td>
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<td>0.8028</td>
<td>1.2442</td>
<td>1.2395</td>
</tr>
<tr>
<td>1 Month Forward</td>
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### The Bid-Ask Spread

- The bid price is the price a dealer is willing to pay you for something.
- The ask price is the amount the dealer wants you to pay for the thing.
- The bid-ask spread is the difference between the bid and ask prices.

### The Bid-Ask Spread

- A dealer could offer:
  - bid price of $1.25 per €
  - ask price of $1.26 per €
- While there are a variety of ways to quote that,
- The bid-ask spread represents the dealer’s expected profit.
The Bid-Ask Spread

A dealer would likely quote these prices as 72-77.
It is presumed that anyone trading $10m already knows the “big figure”.

Bid Ask
1.9072 .5242
1.9077 .5243

Spot FX trading

In the interbank market, the standard size trade is about U.S. $10 million.
A bank trading room is a noisy, active place.
The stakes are high.
The “long term” is about 10 minutes.

Cross Rates

Suppose that $/$€ = 1.50
i.e. $1.50 = €1.00
and that ¥/$€ = 50
i.e. ¥50 = $1.00
What must the ¥/$ cross rate be?

$1.50 ¥1.00
€1.00 ¥50
×
$0.0300 = ¥1

Triangular Arbitrage

Suppose we observe these banks posting these exchange rates.
First calculate any implied cross rate to see if an arbitrage exists.

$1.50 £1.00
¥120 ¥100
×
$0.0300 = ¥1

As easy as 1 – 2 – 3:
1. Sell our $ for £,
2. Sell our £ for ¥,
3. Sell those ¥ for $.

Credit Lyonnais
S(£/$)=1.50
Credit Agricole
S(¥/£)=85
Barclays
S(¥/$)=120

So, how can we make money? Buy the £ @ ¥80; sell @ ¥85.
Then trade yen for your preferred currency.
Triangular Arbitrage

Sell $100,000 for £ at $\( S(£/$) = 1.50 \)
receive £150,000

Sell our £150,000 for ¥ at $\( S(¥/£) = 85 \)
receive ¥12,750,000

Sell ¥12,750,000 for $ at $\( S(¥/$) = 120 \)
receive $106,250

profit per round trip = $106,250 – $100,000 = $6,250

Here we have to go “clockwise” to make money—but it doesn’t matter where we start.

If we went “counter clockwise” we would be the source of arbitrage profits, not the recipient!

Spot Foreign Exchange Microstructure

- Market Microstructure refers to the mechanics of how a marketplace operates.
- Bid-Ask spreads in the spot FX market:
  - increase with FX exchange rate volatility and
  - decrease with dealer competition.
- Private information is an important determinant of spot exchange rates.

The Forward Market

- Forward Rate Quotations
- Long and Short Forward Positions
- Forward Cross Exchange Rates
- Swap Transactions
- Forward Premium

The Forward Market

- A forward contract is an agreement to buy or sell an asset in the future at prices agreed upon today.
- If you have ever had to order an out-of-stock textbook, then you have entered into a forward contract.

Forward Rate Quotations

- The forward market for FX involves agreements to buy and sell foreign currencies in the future at prices agreed upon today.
- Bank quotes for 1, 3, 6, 9, and 12 month maturities are readily available for forward contracts.
- Longer-term swaps are available.
Forward Rate Quotations

Consider the example from above:
for British pounds, the spot rate is
$1.9077 = £1.00
While the 180-day forward rate is
$1.8904 = £1.00
What’s up with that?

Spot Rate Quotations

Clearly the market participants expect that the pound will be worth less in dollars in six months.

Forward Rate Quotations

Consider the (dollar) holding period return of a dollar-based investor who buys £1 million at the spot and sells them forward:

\[
HPR = \frac{\text{gain}}{\text{pain}} = \frac{$1,890,400 - $1,907,700}{$1,907,700} = -0.0091
\]
Annualized dollar HPR = -1.81% = -0.91% × 2

Forward Premium

The interest rate differential implied by forward premium or discount.
For example, suppose the € is appreciating from $/€ = 1.25 to $/€ = 1.30

The 180-day forward premium is given by:
\[
\frac{F_{180} - S}{S} \times 360 = \frac{1.30 - 1.25}{1.25} \times 2 = 0.08
\]

Long and Short Forward Positions

If you have agreed to sell anything (spot or forward), you are “short”.
If you have agreed to buy anything (forward or spot), you are “long”.
If you have agreed to sell FX forward, you are short.
If you have agreed to buy FX forward, you are long.

Payoff Profiles

If you agree to sell anything in the future at a set price and the spot price later falls then you gain.
If you agree to sell anything in the future at a set price and the spot price later rises then you lose.
Payoff Profiles

Whether the payoff profile slopes up or down depends upon whether you use the direct or indirect quote:

\[ F_{180}(¥/$) = 105 \]

\[ F_{180}(¥/$) = 105 \]

short position

When the short entered into this forward contract, he agreed to sell ¥ in 180 days at \( F_{180}(¥/$) = 105 \).

If, in 180 days, \( S_{180}(¥/$) = 120 \), the short will make a profit by buying ¥ at \( S_{180}(¥/$) = 120 \) and delivering ¥ at \( F_{180}(¥/$) = 105 \).

The long in this forward contract agreed to buy ¥ in 180 days at \( F_{180}(¥/$) = 105 \).

If, in 180 days, \( S_{180}(¥/$) = 120 \), the long will lose by having to buy ¥ at \( S_{180}(¥/$) = 120 \) and delivering ¥ at \( F_{180}(¥/$) = 105 \).

Notice that the “$”s cancel.

Forward Cross Exchange Rates

- It's just an “delayed” example of the spot cross rate discussed above.
- In generic terms

\[ F_n(j/k) = F_n(S/k) F_n(S/j) \]

and

\[ F_n(k/j) = F_n(S/j) F_n(S/k) \]

Notice that the “$”s cancel.
### Forward Cross Exchange Rates

<table>
<thead>
<tr>
<th>Currency</th>
<th>USD per Thursday</th>
<th>USD per Friday</th>
<th>Currency per Friday</th>
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<tbody>
<tr>
<td>Argentina (Peso)</td>
<td>0.0008</td>
<td>0.0009</td>
<td>1.2458</td>
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<tr>
<td>Australian Dollar</td>
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<td>Brazilian (Real)</td>
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<td>British Pound</td>
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<td>Japanese Yen</td>
<td>1.2352</td>
<td>1.2382</td>
<td>1.2354</td>
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</tbody>
</table>

The forward pound-Canadian dollar cross rate is calculated as follows:

\[ \text{GBP1.00} \times \frac{\text{USD1.8904}}{\text{CAD1.2412}} = \text{USD1.00} \]

### Currency Symbols

- In addition to the familiar currency symbols (e.g., £, ¥, €, $), there are three-letter codes for all currencies.
- It is a long list, but selected codes include:
  - CHF: Swiss francs
  - GBP: British pound
  - ZAR: South African rand
  - CAD: Canadian dollar
  - JPY: Japanese yen

### SWAPS

- A swap is an agreement to provide a counterparty with something he wants in exchange for something that you want.
- Often on a recurring basis—e.g. every six months for five years.
- Swap transactions account for approximately 56 percent of interbank FX trading, whereas outright trades are 11 percent.
- Swaps are covered fully in Chapter 14.

### Summary

- Spot rate quotations
  - Direct and indirect quotes
  - Bid and ask prices
- Cross Rates
  - Triangular arbitrage
- Forward Rate Quotations
  - Forward premium (discount)
  - Forward points

### Practice Problem

The current spot exchange rate is $1.55/£ and the three-month forward rate is $1.50/£. Based on your analysis of the exchange rate, you are confident that the spot exchange rate will be $1.52/£ in three months. Assume that you would like to buy or sell £1,000,000.

- a. What actions do you need to take to speculate in the forward market? What is the expected dollar profit from speculation?
- b. What would be your speculative profit in dollar terms if the spot exchange rate actually turns out to be $1.46/£?
- c. Graph your results.

### Solution

#### a. If you believe the spot exchange rate will be $1.52/£ in three months, you should buy £1,000,000 forward for $1.50/£. Your expected profit will be:

\[ 20,000 = \text{GBP}1,000,000 \times ($1.52 - $1.50) \]

#### b. If the spot exchange rate actually turns out to be $1.46/£ in three months, your loss from the long position will be:

\[ -40,000 = \text{GBP}1,000,000 \times ($1.46 - $1.50) \]
**Chapter Objective:**
This chapter discusses exchange-traded currency futures contracts, options contracts, and options on currency futures.

### Chapter Outline
- Futures Contracts: Preliminaries
- Currency Futures Markets
- Basic Currency Futures Relationships
- Eurodollar Interest Rate Futures Contracts
- Options Contracts: Preliminaries
- Currency Options Markets
- Currency Futures Options

### Chapter Outline (continued)
- Basic Option Pricing Relationships at Expiry
- American Option Pricing Relationships
- European Option Pricing Relationships
- Binomial Option Pricing Model
- European Option Pricing Model
- Empirical Tests of Currency Option Models
A futures contract is like a forward contract:
- It specifies that a certain currency will be exchanged for another at a specified time in the future at prices specified today.
A futures contract is different from a forward contract:
- Futures are standardized contracts trading on organized exchanges with daily resettlement through a clearinghouse.

Standardizing Features:
- Contract Size
- Delivery Month
- Daily resettlement
- Initial performance bond (about 2 percent of contract value, cash or T-bills held in a street name at your brokerage).

Initial Performance Bond
- About 2 percent of contract value.
- Cash or T-bills held in a street name.

Initial Performance Bond
- $6,500 at initiation.
- $4,000 maintenance level.
- Maintain position by adding more funds.
- Otherwise, position will be closed out with an offsetting short position.

Consider a long position in the CME Euro/U.S. Dollar contract:
- Written on €125,000 and quoted in $ per €.
- Strike price is $1.30.
- Maturity is 3 months.
- At initiation, the long posts an initial performance bond of $6,500.
- Maintenance performance bond is $4,000.

Recall that an investor with a long position gains from increases in the price of the underlying asset.
- Our investor has agreed to BUY €125,000 at $1.30 per euro in three months.
- With a forward contract, at the end of three months, if the euro was worth $1.24, he would lose $7,500.
- If instead at maturity the euro was worth $1.35, the counterparty to his forward contract would pay him $6,250.

With futures, daily resettlement of gains and losses rather than one big settlement at maturity.
- Every trading day:
  - if the price goes down, the long pays the short
  - if the price goes up, the short pays the long
- After the daily resettlement, each party has a new contract at the new price with one-day-shorter maturity.
Daily Resettlement: An Example

- Over the first 3 days, the euro strengthens then depreciates in dollar terms:

<table>
<thead>
<tr>
<th>Settle</th>
<th>Gain/Loss</th>
<th>Account Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.31</td>
<td>$1,250</td>
<td>$7,750 = $6,500 + $1,250</td>
</tr>
<tr>
<td>$1.30</td>
<td>−$1,250</td>
<td>$6,500</td>
</tr>
<tr>
<td>$1.27</td>
<td>−$3,750</td>
<td>$2,750 + $3,750 = $6,500</td>
</tr>
</tbody>
</table>

  On third day suppose our investor keeps his long position open by posting an additional $3,750.

Toting Up

- At the end of his adventures, our investor has three ways of computing his gains and losses:
  - Sum of daily gains and losses:
    - $7,500 = $1,250 + $1,250 + $3,750 − $1,250 − $2,500
  - Contract size times the difference between initial contract price and last settlement price.
    - $7,500 = ($1.24/€ − 1.30/€) × €125,000
  - Ending balance on account minus beginning balance on account, adjusted for deposits or withdrawals.
    - $7,500 = $2,750 − ($6,500 + $3,750)

Currency Futures Markets

- The Chicago Mercantile Exchange (CME) is by far the largest.
- Others include:
  - The Philadelphia Board of Trade (PBOT)
  - The MidAmerica commodities Exchange
  - The Tokyo International Financial Futures Exchange
  - The London International Financial Futures Exchange

The Chicago Mercantile Exchange

- Expiry cycle: March, June, September, December.
- Delivery date third Wednesday of delivery month.
- Last trading day is the second business day preceding the delivery day.
- CME hours 7:20 a.m. to 2:00 p.m. CST.
CME After Hours

- Extended-hours trading on GLOBEX runs from 2:30 p.m. to 4:00 p.m. dinner break and then back at it from 6:00 p.m. to 6:00 a.m. CST.
- The Singapore Exchange offers interchangeable contracts.
- There are other markets, but none are close to CME and SIMEX trading volume.

Reading Currency Futures Quotes

<table>
<thead>
<tr>
<th>Expiry month</th>
<th>Closing price</th>
<th>Daily Change</th>
<th>Highest and lowest prices over the life of the contract</th>
<th>Number of open contracts</th>
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</thead>
<tbody>
<tr>
<td>Mar</td>
<td>1.3170</td>
<td>0.0025</td>
<td>1.3699, 1.1750, 159.822</td>
<td>10,096</td>
</tr>
<tr>
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<td>-0.0025</td>
<td>1.3687, 1.1750, 159.822</td>
<td>600</td>
</tr>
</tbody>
</table>

Basic Currency Futures Relationships

- Open Interest refers to the number of contracts outstanding for a particular delivery month.
- Open interest is a good proxy for demand for a contract.
- Some refer to open interest as the depth of the market. The breadth of the market would be how many different contracts (expiry month, currency) are outstanding.

Reading Currency Futures Quotes

<table>
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</tbody>
</table>

Notice that open interest is greatest in the nearby contract, in this case March, 2005.

In general, open interest typically decreases with term to maturity of most futures contracts.

Basic Currency Futures Relationships

The holder of a long position is committing himself to pay $1.3112 per euro for €125,000—a $163,900 position. As there are 159,822 such contracts outstanding, this represents a notational principal of over $26 billion!

Notice that if you had been smart or lucky enough to open a long position at the lifetime low of $1.1363 by now your gains would have been

$21,862.50 = ($1.3112/€ – $1.1363/€ ) × € 125,000

Bear in mind that someone was unfortunate enough to take the short position at $1.1363!
Basic Currency Futures Relationships

If you had been smart or lucky enough to open a short position at the lifetime high of $1.3687 by now your gains would have been:

$7,187.50 = ($1.3687€ – $1.3112€) × € 125,000

Euro/US Dollar (CME) — €125,000; $ per €

OPEN HIGH LOW SETTLE CHG LIFETIME OPEN HIGH LOW INT

Mar 1.3136 1.3167 1.3098 1.3112 -.0025 1.3687 1.1363 159,822

OPEN HIGH LOW SETTLE CHG LIFETIME OPEN HIGH LOW INT

Jun 1.3170 1.3193 1.3126 1.3140 -.0025 1.3699 1.1750 10,096

Sept 1.3202 1.3225 1.3175 1.3182 -.0025 1.3711 1.1750 600

Recall from chapter 6, our interest rate parity condition:

\[
\frac{1 + r_d}{1 + r_f} = \frac{F(S/E)}{S(F/E)}
\]

From June 15 to September 21, 2005 (the actual delivery dates of these contracts) we should expect higher interest rates in dollar denominated accounts: if we find a higher rate in a euro denominated account, we may have found an arbitrage.

Reading Currency Futures Quotes

Euro/US Dollar (CME) — €125,000; $ per €

OPEN HIGH LOW SETTLE CHG LIFETIME OPEN HIGH LOW INT

Mar 1.3136 1.3167 1.3098 1.3112 -.0025 1.3687 1.1363 159,822

Eurodollar Interest Rate Futures Contracts

- Widely used futures contract for hedging short-term U.S. dollar interest rate risk.
- The underlying asset is a hypothetical $1,000,000 90-day Eurodollar deposit—the contract is cash settled.
- Traded on the CME and the Singapore International Monetary Exchange.
- The contract trades in the March, June, September and December cycle.

Eurodollar futures prices are stated as an index number of three-month LIBOR calculated as \( F = 100 – \text{LIBOR} \).

The closing price for the June contract is 96.56 thus the implied yield is 3.44 percent = 100 – 96.56

Since it is a 3-month contract one basis point corresponds to a $25 price change. 0.1 percent of $1 million represents $100 on an annual basis.

Reading Eurodollar Futures Quotes

Eurodollar (CME) — 1,000,000; pts of 100%

OPEN HIGH LOW SETTLE CHG YLD CHG INT

Jun 96.56 96.58 96.55 96.56 - 3.44 - 1.398,959

Eurodollar Interest Rate Futures Contracts

- Widely used futures contract for hedging short-term U.S. dollar interest rate risk.
- The underlying asset is a hypothetical $1,000,000 90-day Eurodollar deposit—the contract is cash settled.
- Traded on the CME and the Singapore International Monetary Exchange.
- The contract trades in the March, June, September and December cycle.

Options Contracts: Preliminaries

- An option gives the holder the right, but not the obligation, to buy or sell a given quantity of an asset in the future, at prices agreed upon today.
- Calls vs. Puts
  - Call options gives the holder the right, but not the obligation, to buy a given quantity of some asset at some time in the future, at prices agreed upon today.
  - Put options gives the holder the right, but not the obligation, to sell a given quantity of some asset at some time in the future, at prices agreed upon today.
**Options Contracts: Preliminaries**

- **European vs. American options**
  - European options can only be exercised on the expiration date.
  - American options can be exercised at any time up to and including the expiration date.
  - Since this option to exercise early generally has value, American options are usually worth more than European options, other things equal.

- **Intrinsic Value**
  - The difference between the exercise price of the option and the spot price of the underlying asset.

- **Speculative Value**
  - The difference between the option premium and the intrinsic value of the option.

\[
\text{Option Premium} = \text{Intrinsic Value} + \text{Speculative Value}
\]

**Currency Options Markets**

- PHLX
- HKFE
- 20-hour trading day.
- OTC volume is much bigger than exchange volume.
- Trading is in six major currencies against the U.S. dollar.

**Currency Futures Options**

- Are an option on a currency futures contract.
- Exercise of a currency futures option results in a long futures position for the holder of a call or the writer of a put.
- Exercise of a currency futures option results in a short futures position for the seller of a call or the buyer of a put.
- If the futures position is not offset prior to its expiration, foreign currency will change hands.
Currency Futures Options

- Why a derivative on a derivative?
- Transactions costs and liquidity.
- For some assets, the futures contract can have lower transactions costs and greater liquidity than the underlying asset.
- Tax consequences matter as well, and for some users an option contract on a future is more tax efficient.
- The proof is in the fact that they exist.

Basic Option Pricing Relationships at Expiry

- At expiry, an American call option is worth the same as a European option with the same characteristics.
- If the call is in-the-money, it is worth \( S_T - E \).
- If the call is out-of-the-money, it is worthless.

\[ C_{it} = C_{eT} = \text{Max}(S_T - E, 0) \]

Basic Option Pricing Relationships at Expiry

- At expiry, an American put option is worth the same as a European option with the same characteristics.
- If the put is in-the-money, it is worth \( E - S_T \).
- If the put is out-of-the-money, it is worthless.

\[ P_{at} = P_{eT} = \text{Max}(E - S_T, 0) \]

Basic Option Profit Profiles

- Long 1 call
  - If the call is in-the-money, it is worth \( S_T - E \).
  - If the call is out-of-the-money, the writer keeps the option premium.

- Short 1 call
  - If the call is in-the-money, the writer loses \( S_T - E \).
  - If the call is out-of-the-money, the writer keeps the option premium.

Basic Option Profit Profiles

- Long 1 put
  - If the put is in-the-money, it is worth \( E - p_0 \).
  - The maximum gain is \( E - p_0 \).
  - If the put is out-of-the-money, it is worthless and the buyer of the put loses his entire investment of \( p_0 \).

- Short 1 put
  - If the put is in-the-money, the writer loses \( E - p_0 \).
  - If the put is out-of-the-money, the writer keeps the option premium.
Basic Option Profit Profiles

If the put is in-the-money, it is worth \( E - S_T \). The maximum loss is \( -E + p_0 \).
If the put is out-of-the-money, it is worthless and the seller of the put keeps the option premium of \( p_0 \).

Example

- Consider a call option on £31,250.
- The option premium is $0.25 per pound.
- The exercise price is $1.50 per pound.

Example

- Consider a put option on £31,250.
- The option premium is $0.15 per pound.
- The exercise price is $1.50 per pound.

American Option Pricing Relationships

- With an American option, you can do everything that you can do with a European option AND you can exercise prior to expiry—this option to exercise early has value, thus:

\[
C_{at} \geq C_{eT} = \max(S_T - E, 0)
\]

\[
P_{at} \geq P_{eT} = \max(E - S_T, 0)
\]

Market Value, Time Value and Intrinsic Value for an American Call

The red line shows the payoff at maturity, not profit, of a call option. Note that even an out-of-the-money option has value—time value.

Example

- Consider a call option on £31,250.
- The option premium is $0.25 per pound.
- The exercise price is $1.50 per pound.

Example

- Consider a put option on £31,250.
- The option premium is $0.15 per pound.
- The exercise price is $1.50 per pound.

Example

What is the maximum gain on this put option?
At what exchange rate do you break even?
European Option Pricing Relationships

Consider two investments

1. Buy a European call option on the British pound futures contract. The cash flow today is \(-C_e\).
2. Replicate the upside payoff of the call by
   1. Borrowing the present value of the exercise price of the call in the U.S. at \(i_\$\).
      The cash flow today is \(\frac{E}{(1 + i_\$)}\).
   2. Lending the present value of \(S_T\) at \(i_\£\).
      The cash flow today is \(-\frac{S_T}{(1 + i_\£)}\).

When the option is in-the-money both strategies have the same payoff.
When the option is out-of-the-money it has a higher payoff than the borrowing and lending strategy.
Thus:
\[
C_e \geq \text{Max} \left( \frac{S_T}{(1 + i_\£)} - \frac{E}{(1 + i_\$)}, 0 \right)
\]

European Option Pricing Relationships

Using a similar portfolio to replicate the upside potential of a put, we can show that:
\[
P_e \geq \text{Max} \left( \frac{E}{(1 + i_\$)} - \frac{S_T}{(1 + i_\£)}, 0 \right)
\]

Binomial Option Pricing Model

- A call option on the euro with exercise price \(S_0(\$/\£) = \$1\) will have the following payoffs.

<table>
<thead>
<tr>
<th>(S_0($/\£))</th>
<th>(S_T($/\£))</th>
<th>(C_T($/\£))</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.10</td>
<td>$1</td>
<td>$0.10</td>
</tr>
<tr>
<td>$1.10</td>
<td>$.90</td>
<td>$0</td>
</tr>
</tbody>
</table>

- We can replicate the payoffs of the call option. With a levered position in the euro.

<table>
<thead>
<tr>
<th>(S_0($/\£))</th>
<th>(S_T($/\£))</th>
<th>(C_T($/\£))</th>
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</tr>
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<td>$.90</td>
<td>$0</td>
</tr>
</tbody>
</table>
Binomial Option Pricing Model

Borrow the present value of $.90 today and buy €1. Your net payoff in one period is either $.2 or $0.

\[
\begin{array}{|c|c|c|c|}
\hline
S_0(\$/€) & S_1(\$/€) & debt portfolio C_1(\$/€) \\
\hline
$1 & $1.10 & $0.20 & $0.10 \\
\hline
$0.90 & $0.90 & $0.00 & $0 \\
\hline
\end{array}
\]

The portfolio has twice the option’s payoff so the portfolio is worth twice the call option value.

\[
\begin{array}{|c|c|c|c|}
\hline
S_0(\$/€) & S_1(\$/€) & debt portfolio C_1(\$/€) \\
\hline
$1 & $1.10 & $0.20 & $0.10 \\
\hline
$0.90 & $0.90 & $0.00 & $0 \\
\hline
\end{array}
\]

The portfolio value today is today’s value of one euro less the present value of a $.90 debt: 

\[
S_0(\$/€) - \frac{.90}{(1 + i)}
\]

The spot exchange rate is of course $1.00 = €1.00 (which makes this option at-the-money).

The most important lesson from the binomial option pricing model is:

- the replicating portfolio intuition.

- Many derivative securities can be valued by valuing portfolios of primitive securities when those portfolios have the same payoffs as the derivative securities.

Find the value of a one-year at-the-money call option on the dollar with a strike price in euro. The correct discount rate is \( i = 2\% \) and in one year there are only two possibilities: €1.00 = $0.80 or €1.00 = $1.25.

- The spot exchange rate is of course $1.00 = 1.00 (which makes this option at-the-money).
Solution

European Option Pricing Formula

We can use the replicating portfolio intuition developed in the binomial option pricing formula to generate a faster-to-use model that addresses a much more realistic world.

Two points:
1. You may be used to thinking in terms of dollars and not euros.
2. The replicating portfolio isn’t always twice as valuable as the call.

Two points:
1. You may be used to thinking in terms of dollars and not euros.
2. The replicating portfolio isn’t always twice as valuable as the call.

European Option Pricing Formula

The model is

\[ C_0 = [F \times N(d_1) - E \times N(d_2)]e^{-rT} \]

Where:
- \( C_0 \) is the value of a European option at time \( t = 0 \)
- \( F \) is the exchange rate at \( t = 0 \)
- \( E \) is the exercise price
- \( r \times T \) is the interest rate available in the U.S.
- \( r \times T \) is the interest rate available in the foreign country
- \( d_1 \) and \( d_2 \) are calculated using the formula:

\[ \begin{align*}
    d_1 &= \frac{\ln(F/E) + (r \times T)}{\sigma \sqrt{T}} \\
    d_2 &= d_1 - \sigma \sqrt{T}
\end{align*} \]

European Option Pricing Formula

Find the value of a six-month call option on the British pound with an exercise price of \$1.50 = £1
The current value of a pound is \$1.60
The interest rate available in the U.S. is \( r_s = 5\% \).
The interest rate in the U.K. is \( r_E = 7\% \).
The option maturity is 6 months (half of a year).
The volatility of the $/£ exchange rate is 30% p.a.
Before we start, note that the intrinsic value of the option is \$0.10—our answer must be at least that.

European Option Pricing Formula

Let’s try our hand at using the model. If you have a calculator handy, follow along.
First calculate

\[ F = S e^{(r_s - r_E)T} = 1.50 e^{0.05 \times 0.5} = 1.485075 \]

Then, calculate \( d_1 \) and \( d_2 \):

\[ \begin{align*}
    d_1 &= \frac{\ln(F/E) + 0.5 \times 0.5}{0.3 \sqrt{0.5}} = \frac{\ln(1.485075/1.5) + 0.5(0.415)}{0.3 \sqrt{0.5}} = 0.106066 \\
    d_2 &= d_1 - \sigma \sqrt{T} = 0.106066 - 0.3 \times 0.5 = -0.176878
\end{align*} \]

European Option Pricing Formula

\[ \begin{align*}
    N(d_1) &= N(0.106066) = 0.5422 \\
    N(d_2) &= N(-0.1768) = 0.4298 \\
    C_0 &= [F \times N(d_1) - E \times N(d_2)]e^{-rT} \\
    C_0 &= [1.485075 \times 0.5422 - 1.50 \times 0.4298]e^{-0.05 \times 0.5} = 0.157
\end{align*} \]
Option Value Determinants

<table>
<thead>
<tr>
<th></th>
<th>Call</th>
<th>Put</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Exchange rate</td>
<td>+</td>
</tr>
<tr>
<td>2.</td>
<td>Exercise price</td>
<td>–</td>
</tr>
<tr>
<td>3.</td>
<td>Interest rate in U.S.</td>
<td>+</td>
</tr>
<tr>
<td>4.</td>
<td>Interest rate in other country</td>
<td>+</td>
</tr>
<tr>
<td>5.</td>
<td>Variability in exchange rate</td>
<td>+</td>
</tr>
<tr>
<td>6.</td>
<td>Expiration date</td>
<td>+</td>
</tr>
</tbody>
</table>

The value of a call option $C_0$ must fall within
\[ \max (S_0 - E, 0) \leq C_0 \leq S_0 \]
The precise position will depend on the above factors.

Empirical Tests

The European option pricing model works fairly well in pricing American currency options.

It works best for out-of-the-money and at-the-money options.

When options are in-the-money, the European option pricing model tends to underprice American options.

End Chapter Seven