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Pricing Financial Futures Contracts: An Introduction

I. Introduction

Financial futures contracts are among the most actively traded securities. The volume of financial futures contracts traded each day, measured in dollars, exceeds the daily volume of trading in stocks. Contracts representing more than 1.7 trillion dollars in stocks were traded in the Chicago Mercantile Exchange's S&P 500 futures pit during 1986. The annual volume in the Treasury bond futures pit at the Chicago Board of Trade for 1986 was more than 5.2 trillion dollars. In contrast, the total volume for all stocks on the New York Stock Exchange was only 1.4 trillion dollars in 1986.

A futures contract is a commitment made today to purchase an asset in the future. All terms of the trade are agreed on when the contract is initiated. For example, in March two investors might initiate a September Swiss franc futures contract with a price of $ 0.50 per franc. One trader (called the short) agrees to deliver 125 000 Swiss francs in September and the other trader (called the long) agrees to pay $ 62 500 (125 000 × $ 0.50) in September. No money changes hands when the contract is initiated; payment occurs on delivery.

The current (spot) price and the futures price for an asset differ for two reasons. First, in the spot market, the buyer must pay for his purchase today. In the futures market, the buyer pays for the asset when the contract matures. The delayed payment in the futures market allows the buyer to earn interest on his money over the life of the contract, and it tends to increase the futures price relative to the spot price.

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Second, purchases in the spot market entitle the buyer to all future dividend or coupon payments. With a delayed purchase in the futures market, the buyer does not receive any dividend or coupon payments that are made before the contract matures. This reduces the benefits of a delayed purchase and lowers the futures price.

In section II, I illustrate the basic ideas by examining the delayed sale of a painting. In the remaining sections, I use these concepts to price futures contracts on stock indexes, Treasury bills, Treasury bonds, and foreign currencies. I ignore several complications, including taxes, transactions costs, and daily settling-up in the futures market. Although these factors do affect futures prices, the simple relations summarized below provide a good description of the prices observed in the trading pits.

II. The Basic Idea

The owner of a valuable art collection is about to sell a painting by van Gogh for $ 1 000 000 when the buyer asks to delay the sale. The buyer wants to sign a contract today to buy the painting in six months. Although the contract would specify the purchase price and the delivery date, neither payment nor delivery would take place for six months. What is the minimum price the owner of the painting should accept for this delayed sale?

A. No Costs or Benefits of Holding the Painting

The answer depends on the interest rate and the costs (or benefits) of holding the painting for six months. Suppose the interest rate is 8% per year or 4% over six months. Also, suppose the costs and benefits of holding the painting are small enough that they can be ignored. Finally, suppose the seller is confident that the buyer will fulfil his commitment in six months.

Since the owner could sell the painting today for $ 1 000 000, put the money in the bank, and receive $ 1 040 000 ($ 1 000 000 × 1.04) in six months, he should not accept the delayed sale unless the fixed future price is at least $ 1 040 000. If the owner agrees to the delayed sale, he loses the interest on the money he could have received today. Thus, the price on the delayed sale must be at least the current price, $ 1 000 000, plus interest, $ 40 000.

Immediate Sale for $1 000 000

$1 000 000 — Earn 4% in the bank → $1 040 000

today — 6 months

Delayed Sale for $1 040 000

$1 040 000

today — 6 months

What is the highest price the buyer should be willing to pay in the delayed sale? If the buyer accepts the delayed sale, he keeps his $ 1 000 000 for an extra six months. The six-month interest rate is 4%, so his money will grow to $ 1 040 000 ($ 1 000 000 × 1.04). The buyer should accept a delayed price up to $ 1 040 000. If the delayed price is higher, he is better off buying the painting today.

The seller will not accept a delayed price below $ 1 040 000, and the buyer will not accept a delayed price above $ 1 040 000. If the current (spot) price S is $ 1 000 000 and the six-month interest rate R is 4%, the delayed (futures) price F must be $ 1 040 000,

$$F = S \times (1 + R).$$

The buyer pays nothing until delivery, so the delayed price equals the future value of the current price.

B. Dividends from Owning the Painting

The appropriate price in the delayed sale is different if the costs or benefits of holding the painting are substantial. For example, suppose the current owner is planning to exhibit his collection in six months. If the sale of the van Gogh is delayed, the owner can include the painting in the exhibit and increase his ticket sales by $ 10 000. How does this affect the price he is willing to accept in the delayed sale?

If the owner sells the painting today for $ 1 000 000, he can put the money in the bank and earn 4% over the next six months; he will have $ 1 040 000 ($ 1 000 000 × 1.04) in six months. If the sale is delayed, the owner will receive the delayed price and an additional $ 10 000 in ticket sales in six months. The owner should not accept a delayed price below $ 1 030 000 ($ 1 040 000 – 10 000).

Suppose the owner will exhibit his collection in three, rather than six, months. In this case the owner will accept an even lower delayed price. If the annual interest rate is 8%, the additional $ 10 000 ticket revenues will grow by 2%, to $ 10 200, over the three months before the delayed sale. Thus, the owner should be willing to accept a delayed sale price of $ 1 029 800 ($ 1 040 000 – 10 200).

Immediate Sale for $1 000 000

$1 000 000 — Earn 4% in the bank → $1 040 000

today — 6 months

Exhibit and Delayed Sale

Delayed Sale		$1 029 800
Exhibit	$10 000 — 2% →	10 200
Total		$1 040 000

today — 3 months — 6 months

If the owner receives benefits (dividends) from holding the asset, the delayed price is reduced by the future value of the benefits D,

$$\begin{aligned} F &= S \times (1 + R) - D \\ &= \$\,1\,000\,000 \times 1.04 - \$\,10\,200 \\ &= \$\,1\,029\,800. \end{aligned}$$

By delaying the purchase, the buyer can earn interest on the spot price, but he forfeits the benefits of ownership. Thus, the delayed price equals the cumulated value of the spot price minus the cumulated value of the benefits.

III. Pricing Stock Index Futures

A stock index futures contract is similar to the delayed sale of a painting. In essence, one trader, like the seller in the example above, agrees to deliver the stock index when the contract matures. The other trader, analogous to the buyer, agrees to pay the futures price at that time[1].

A. Non-Dividend-Paying Stocks

Like the delayed price of a painting, the futures price for a stock index contract depends on the interest rate and the dividends that accrue to the owner of the underlying portfolio. If none of the stocks in the portfolio pays dividends, the futures price is just the future value of the current level of the index.

Consider an investor comparing an immediate sale of his stocks in March with a delayed sale in September. Suppose the current value of his portfolio is $ 210.00, and the six-month interest rate (from March to September) is 5%[2]. What is the minimum price the investor should accept to sell his portfolio using a September futures contract? If the investor sells his portfolio today, he can invest the revenue for six months at 5% and receive $ 220.50 ($ 210.00 × 1.05) in September. Thus, he should not accept the delayed sale (futures contract) unless the futures price is at least $ 220.50.

Immediate Sale for $ 210.00

$ 210.00	— Earn 5% in the bank →	$ 220.50
March		September

Delayed Sale (September Futures Contract) for $ 220.50

	$ 220.50
March	September

What about an investor who wants to buy the portfolio of stocks? He can buy it in the spot market today for $ 210.00. Or he can put his money in the bank and take a long September futures position, agreeing to buy the portfolio in September. The six-month interest rate is 5%, so a deposit of $ 210.00 today will grow to $ 220.50 ($ 210.00 × 1.05) in September. The investor is better off with a delayed purchase if the futures price is less than $ 220.50. If the futures price is above $ 220.50, the investor should buy the portfolio in the spot market.

Since sellers are unwilling to accept a delayed price below $ 220.50, and buyers are unwilling to accept a delayed price above $ 220.50, the September futures price must be $ 220.50.

More generally, define F(t, T) as the futures price now (time t) for a contract that matures later (at time T), define S(t) as the current portfolio or index value, and define R(t, T) as the interest rate over the life of the futures contract. The futures price for an index on *non-dividend-paying stocks* must be the current index value times one plus the interest rate,

$$
\begin{aligned}
F(t, T) &= S(t) \times [1 + R(t, T)] \\
&= 210.00 \times 1.05 \\
&= 220.50.
\end{aligned}
$$

B. The Effect of Dividends

If an investor sells his stocks in the spot market, he is not entitled to any dividends that are paid in the future. If he makes a delayed sale in the futures market, he receives all of the dividends paid before his futures contract matures. Thus, dividends are like the additional ticket revenue in the example above. They increase the benefits of a delayed sale and reduce the futures price the seller is willing to accept.

Suppose the stocks in the investor's portfolio will pay $ 5.00 in September, just before the futures contract matures. He can sell his portfolio today for $ 210.00, invest the money at 5% for six months, and receive $ 220.50 in September. Alternatively, he can take a short futures position, promising to deliver the portfolio in six months. In September he receives not only the futures price, but also $ 5.00 in dividends. The investor is better off with a delayed sale if the futures price is above $ 215.50 ($ 220.50 – 5.00).

Immediate Sale for $ 210.00

$ 210.00	— Earn 5% in the bank →	$ 220.50
March		September

Delayed Sale (September Futures Contract) for $ 215.50

Dividends	$ 5.00
Futures Price	215.50
Total	$ 220.50
March	September

An investor purchasing the portfolio makes the same comparison. If he buys the portfolio in the spot market, he pays $ 210.00 today. In September, he has the portfolio plus a dividend of $ 5.00. If he buys the portfolio in the futures market, he can keep his money in the bank until September, but he does not receive the dividend. By September, his money will have grown to $ 220.50 ($ 210.00 × 1.05). After completing the delayed purchase, he will have the portfolio plus the difference between $ 220.50 and the futures price. The investor should buy in the spot market if this difference is less than $ 5.00 or, equivalently, if the futures price is above $ 215.50 ($ 220.50 – 5.00).

Immediate Purchase $ 210.00

Spot Price	– $ 210.00	
Dividends		$ 5.00
March		September

Delayed Purchase (September Futures Contract) for $ 215.50

Bank Deposit	– $ 210.00 — 5 % interest →	$ 220.50
Futures Price		– 215.50
Total		$ 5.00
	March	September

In general, the futures price is reduced by the maturity value of the dividends paid over the life of the contract. Suppose the portfolio of stocks will pay a $ 10.00 dividend tomorrow and a $ 5.00 dividend in six months. Again, the owner can sell the portfolio today for $ 210.00, put the money in the bank, and receive $ 220.50 in September. Or he can make a delayed sale in the futures market. In this case, he receives $ 10.00 in dividends tomorrow, plus $ 5.00 in dividends and the futures price in September. Tomorrow's dividends grow to $ 10.50 ($ 10.00 × 1.05) in six months, so his total revenue in September is $ 15.50 ($ 10.50 + 5.00) plus the futures price. If the futures price is $ 205.00 ($ 220.50 – 15.50), the seller is indifferent between an immediate sale in the spot market and a delayed sale in the futures market.

More generally, define D(t, T) as the maturity value of the dividends paid over the life of the futures contract, from time t to T. The price for a stock index futures contract is the accumulated value of the index minus the maturity value of the dividends,

$$
\begin{aligned}
F(t, T) &= S(t) \times [1 + R(t, T)] - D(t, T) \\
&= 210.00 \times 1.05 - 10.00 \times 1.05 - 5.00 \\
&= 205.00.
\end{aligned}
$$

IV. Pricing Treasury Bill Futures

As the name suggests, a Treasury bill futures contract is a delayed sale of a United States Treasury bill. One trader agrees to deliver a Treasury bill when the contract matures, and the other agrees to pay the futures price. The standard contract requires delivery of bills that will mature three months after delivery. For example, a futures contract that matures in September requires delivery of bills that mature in December.

Since the owner of a Treasury bill receives no payments before the bill matures, a Treasury bill futures contract is similar to a stock index futures contract on non-dividend-paying stocks. The spot and futures prices differ only because of the delayed payment in the futures contract.

Consider an investor comparing an immediate and a delayed sale of a nine-month Treasury bill. Suppose the six-month interest rate (from March to September) is 5 % and the nine-month interest rate (from March to December) is 7 %[3]. The investor can sell his nine-month (December) bills today for $ 93.46 ($ 100/1.07) per $ 100 face value, deposit the revenue in the bank, and receive $ 98.13 ($ 93.46 × 1.05) in September. Alternatively, the investor might take a short September Treasury bill futures position, promising to sell his December bills in September. Since an immediate sale will generate $ 98.13 in September, the investor should not accept a delayed sale unless the futures price is at least $ 98.13.

Immediate Sale for $ 93.46

$ 93.46 — Earn 5 % on bank deposit → $ 98.13

March — September

Delayed Sale (September Futures Contract) for $ 98.13

$ 98.13

March — September

Similarly, a buyer who purchases December bills in the futures markets retains the use of his funds until the contract matures. He can buy the bills today for $93.46 ($100.00/1.07). Or he can deposit this money in the bank and take a long futures position, agreeing to buy December bills in September. The bank deposit will grow to $98.13 ($93.46 × 1.05) in September, so he should be willing to accept any futures price up to $98.13.

The seller will not accept a delayed price below $98.13, and the buyer will not accept a price above $98.13, so the futures price must be $98.13. More generally, define F(t, T) as the futures price at time t for a contract that matures at T, define S(t) as the spot price at t for the deliverable Treasury bill, and define R(t, T) as the interest rate over the life of the futures contract. Because of the delayed payment in the futures market, the futures price is the future value of the current spot price,

$$\begin{aligned} F(t, T) &= S(t) \times [1 + R(t, T)] \\ &= \$93.26 \times 1.05 \\ &= \$98.13. \end{aligned}$$

This is identical to the relation between the spot and futures prices for a contract on non-dividend-paying stocks.

V. Treasury Bond Futures

Treasury bond futures contracts are a very popular tool for managing interest rate risk. Approximately one quarter of all futures contracts traded in 1986 were traded in the Chicago Board of Trade Treasury bond futures pit. Nominally, a Treasury bond futures contract calls for delivery of bonds with 8% annual coupon payments, $100000 face value, and 20 years to maturity when the contract matures.

The relation between spot and futures prices for Treasury bond futures is similar to the relation for stock index futures on dividend-paying stocks. Delayed payment in the futures market increases the futures price, while coupon payments in the spot market reduce the futures price. However, the pricing of Treasury bond futures contracts is complicated slightly by accrued interest; although the buyer must pay accrued interest, it is not included in the quoted spot and futures prices.

Treasury bond coupons are paid semi-annually. After a coupon is paid, interest accrues until the next coupon payment. For example, an 8% bond with a face value of $100000 pays a coupon of $4000 ($100000 × 4%) every six months. If there are 182 days between coupons, the accrued interest grows by $21.98 ($4000/182) each day. An investor buying the bond on the day after a coupon must pay the quoted price plus $21.98. An investor buying the bond 100 days after a coupon payment must pay the quoted price plus $2198.00.

If one includes accrued interest, the relation between the actual payments in the Treasury bond spot and futures markets is identical to the relation between the spot and futures prices for stock index futures. The futures payment FP(t, T) is the accumulated value of the spot payment SP(t) minus the maturity value of the coupons over the life of the contract C(t, T),

$$FP(t, T) = SP(t) \times [1 + R(t, T)] - C(t, T).$$

The spot payment SP(t) is the quoted spot price S(t), plus the current accrued interest on the deliverable bond i(t). The futures payment FP(t, T) is the futures price F(t, T), plus the accrued interest on the deliverable bond at delivery i(T). Using the relation between the spot and futures payments,

$$F(t, T) + i(T) = [S(t) + i(t)] \times [1 + R(t, T)] - C(t, T),$$

the Treasury bond futures price is[4]

$$F(t, T) = [S(t) + i(t)] \times [1 + R(t, T)] - C(t, T) - i(T).$$

For example, consider an investor who is trying to decide whether to buy an 8% Treasury bond in the spot or futures market. The bond pays coupons on May 15 and October 15. If the quoted spot price on May 20 is $103.00 per $100.00 face value, he can buy the bond for $103.000.00 plus accrued interest of $109.90 ($21.98 × 5). Alternatively, he can deposit this money in the bank and make a delayed purchase using a September futures contract. What is the highest price he should accept in the futures market?

Since there is no coupon payment on the bond before the contract matures, the only issue is whether the bank deposit will pay both the futures price and the accrued interest when the contract matures. Suppose the interest rate from May to September is 2%, so the deposit will grow to $105172.10 ($103109.90 × 1.02) in September. If the contract matures on September 1, the accrued interest is $2395.82 ($21.98/day × 109 days between May 15 and September 1). Thus, the investor should be willing to accept any futures price less than or equal to $102776.28 ($105172.10 – 2395.82).

Using the relation above,

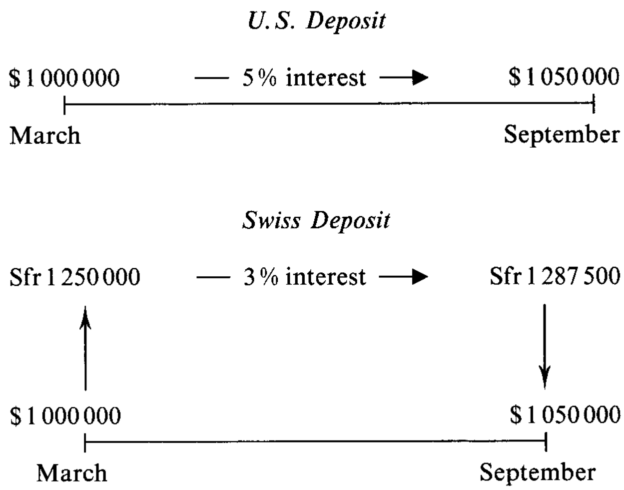
$$
\begin{aligned}
F(t,T) &= [S(t) + i(t)] \times [1 + R(t,T)] - C(t,T) - i(T) \\
&= [\$103\,000.00 + 109.90] \times 1.02 - 0.00 \\
&\quad - 2395.82 \\
&= \$102\,776.28.
\end{aligned}
$$

VI. Foreign Currency Futures

A foreign currency futures contract is a commitment to exchange a specific quantity of some currency for U.S. dollars at a specific time in the future. For example, a September Swiss franc futures contract commits the short to deliver 125000 Swiss francs in September and it commits the long to pay the futures price for each franc.

Foreign currency traders price futures contracts using the concept of interest rate parity. Interest rate parity implies that, after adjusting for exchange rate differences, interest rates must be equal across countries. Consider an investor planning to invest dollars in March to obtain dollars in September. The simple approach is to deposit his money in a U.S. bank in March and then to withdraw the money in September. Alternatively, he can exchange his dollars for Swiss francs today, deposit the francs in a Swiss bank, and take a short futures position, promising to exchange francs for dollars in September. The return from these two riskless strategies must be identical.

Suppose the current exchange rate is $0.80 per Swiss franc, the dollar interest rate from March to September is 5% and the Swiss franc interest rate is 3%. If he chooses, the investor can a) exchange $1000000 for 1250000 ($1000000/$0.80) Swiss francs today, b) deposit this money in a Swiss bank, c) withdraw 1287500 (1250000 × 1.03) francs in September, and d) sell these francs in the futures market for 1287500 times the futures price. Since he can get $1050000 ($1000000 × 1.05) by depositing his money in a U.S. bank, the Swiss franc approach is preferable if the futures price is above $0.8155 ($1050000/1287500).



For example, suppose the September futures price is $0.90. By committing to a delayed sale of francs in the futures market, the investor can lock in a payment of $1158750 ($0.90 × 1287500) in September for $1000000 today. This riskfree return of almost 16% dominates the domestic interest rate, so anyone planning to lend money in the U.S. would prefer to combine a short futures position with lending in Switzerland. This would put pressure on the futures price until it fell to $0.8155.

Alternatively, suppose the futures price is below $0.8155. Then anyone planning to lend money in Switzerland would be better off a) converting their francs to dollars, b) depositing them in a U.S. bank, and c) taking a long futures position to convert the dollars to francs in September. The demand for long futures positions would drive the futures price back up to $0.8155.

More generally, define S(t) as the current price in dollars of the foreign currency (the exchange rate), define R(t, T) as the domestic (U.S.) interest rate from t to T, and define R*(t, T) as the foreign interest rate from t to T. Then the futures price at t for a contract that matures at T is

$$
\begin{aligned}
F(t,T) &= S(t) \times [1 + R(t,T)]/[1 + R^*(t,T)] \\
&= \$0.80 \times 1.05/1.03 \\
&= \$0.8155.
\end{aligned}
$$

The futures price for foreign currency contracts is determined by the same two factors that determine the prices for other financial futures contracts. An investor can buy Swiss francs today at the current exchange rate. Alternatively, he can make a delayed purchase in the futures market, promising to pay the futures price when the contract matures. Because of the delayed payment in the futures market, the futures price is increased by the U. S. interest rate. However, with the delayed purchase, the investor forfeits the interest he could earn on the Swiss francs if he bought them today. This interest is similar to dividends or coupon payments forfeited by traders in the stock index and Treasury bond futures markets. It reduces the price the investor is willing to pay in the delayed purchase.

For example, suppose the U. S. interest rate is 30% and the Swiss interest rate is 1%. By making a delayed purchase, the investor can invest his dollars at a high interest rate before the contract matures, and he gives up little by not having francs to invest. The difference in interest rates makes the delayed purchase attractive and raises the futures price. On the other hand, suppose the U. S. interest rate is 1% and the Swiss interest rate is 30%. There is little return from investing dollars before the delayed payment and the cost of not having francs to invest is high. This difference makes the delayed purchase unattractive and lowers the futures price.

VII. Institutional Environment and Empirical Accuracy

In developing the relation between spot and futures prices, I have assumed that the only cashflow occurs when the contract matures. In fact, there is a daily transfer, or settling-up, between the traders. After each day's trading, the futures price is compared with the closing price from the previous day. If the price has fallen, the investor who is long (committing himself to purchase the asset) must pay the short the amount of the decrease. If the futures price has risen, the long receives the increase from the short. After this transfer, the contract is 'marked-to-market', or rewritten at the current price.

Daily settling-up reduces the likelihood that either trader will default and it reduces the costs if a trader does default. Without settling-up, a trader's losses can cumulate over the life of the contract. Daily settling-up limits this exposure to one day's price change. This protection is not free. The daily transfer of profits and losses increases bookkeeping costs and it forces traders to hold liquid assets. Apparently, the benefits of daily settling-up usually outweigh the costs.

There are a few forward markets that do not settle up daily. The most prominent is the interbank foreign currency market. This market is only available to banks and large corporations. Presumably, the creditworthiness of these firms is sufficient to guarantee their financial performance; there is little reason to bear the transactions costs of daily settling-up. On the other hand, individuals and small corporations wishing to trade foreign currencies must transact on futures exchanges, such as the International Monetary Market at the Chicago Mercantile Exchange. Because of the higher default risk of these traders, the futures contracts are settled daily.

Daily settling-up appears to have little impact on the relation between spot and futures prices. CORNELL and REINGANUM (1981) compare the prices for foreign exchange forward contracts (without daily settling-up) and futures contracts (which are settled daily). They find small random differences between the forward and futures prices. Similarly, FRENCH (1983) reports small differences between forward and futures prices for copper and silver.

Transactions costs have a larger impact on the accuracy of the pricing relations described above. In general, arbitragers insure that the actual futures price will be close to the theoretical price described by the relations above. For example, suppose the actual Swiss franc futures price is high relative to the theoretical price. Then an arbitrager can lock in a profit by shorting the futures contract and buying Swiss francs. This will drive the futures price up relative to the spot price and bring the actual futures price closer to the theoretical price. When the futures price is too low, buying pressure drives the price up. Arbitrage will continue until any potential profits are eliminated by transactions costs.

In general, transactions costs are relatively low and the actual futures price is close to the theoretical futures price. For example, foreign currency futures prices are almost always within 1% of their theoretical value. Typical transactions costs for arbitrage in the stock index market are about 0.5%; under normal circumstances, index arbitrage will force the futures price to remain within 0.5% of the value described above. However, these tight arbitrage bounds were ravaged on Black Monday, October 19, 1987. Because of enormous trading pressures at the stock and futures exchanges, the effective transaction costs for index arbitrage were substantially higher on both October 19 and 20. These transactions costs, in turn, precluded arbitragers from exploiting differences as large as 10 or 15%, between the actual and theoretical futures prices. Fortunately, pricing errors of this size are as rare as the price changes that precipitated them.

VII. Summary

The relation between spot and futures prices for financial futures contracts is determined by two factors. With a delayed purchase in the futures market, a buyer retains the use of his funds before the contract matures. This increases the futures price he is willing to accept. However, the buyer forfeits any dividends or coupons that are paid to the owner of the asset before the contract matures. This reduces the futures price he is willing to accept.

In the special case of foreign currency futures, interest payments on the foreign currency increase the quantity of the deliverable asset. Therefore, the adjustment for these 'dividends' is multiplicative,

$$F(t, T) = S(t) \times [1 + R(t, T)]/[1 + R^*(t, T)].$$

For all other financial futures contracts, the futures price equals the maturity value of the current spot price, minus the maturity value of any dividends or coupons that are paid over the life of the contract,

$$F(t, T) = S(t) \times [1 + R(t, T)] - D(t, T).$$

Footnotes

[1] Because of the large transactions costs involved in delivering all of the stocks in the index in exactly the right proportions, stock index futures actually use cash settlement, rather than physical delivery. If the index is above the futures price at maturity, the buyer receives the difference from the seller. If the index is below the futures price, the seller receives the difference. Cash settlement is equivalent to having the seller 'deliver' the maturity value of the index, and having the buyer pay the futures price.

[2] Note that 5% is not an annualized interest rate. An investor who deposits $1.00 in the bank in March receives $1.05 in September.

[3] Again, 7% is not an annualized interest rate. An investor who puts $1.00 in nine-month bills in March receives $1.07 in December. Treasury bill spot and futures prices are quoted on an annualized discount basis. For example, suppose the actual price on a 90-day bill is $98.00 (per $100.00 face value). The annualized discount is ($100.00 – 98.00) × 360/90 = $8.00, and the quoted price is $100.00 – 8.00 = $92.00. The annualized discount complicates the relation between the quoted spot and futures prices, so I concentrate on actual, rather than quoted, prices.

[4] This discussion ignores the delivery options available to the seller in the Treasury bond futures contract. See Gay and Manaster (1986).

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