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Financial engineering and arbitrage in the financial markets

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Financial Engineering and Arbitrage in the Financial Markets

To Britt, Elsa, Ethan, and illy

Introduction

This book is an update and an improvement on my original 2004 book.

The update is the discussion of the many new things that happened in the last 10 years. Hedge funds took over the relative value strategies instead of relying on sell-side dealers pitching structured products. Credit derivatives (default swaps and collateralized debt obligations) became part of the standard tool-kit. Statistical arbitrage and tactical asset allocation edged out a lot of buy-and-hold funds. Indexing has undergone a near revolution to include new asset classes and strategies.

The improvement is in the presentation. The method of the original book was to present the difficult subjects of arbitrage, derivative pricing, and financial engineering in terms of numbers – cash flow discounting, binomial trees, tables, and diagrams – rather than differential equations. This book follows that appealing formula. All examples are worked out numerically, but they are now enhanced with flow diagrams, and are connected across the markets and chapters. Another big improvement, hopefully, is the division of the book into three parts, each offering a different perspective. If you watched three boys play with Lego, you would want to know the types of blocks (colors, the number of pegs, etc.) they are playing with, what they are building with them (a robot or a fire station), and why each boy is playing. The three parts of this book are just like that: Part I is the basic spot, futures, swap, and option transactions as building blocks; Part II illustrates examples of engineering those building blocks into CDOs or mortgage-backed securities (MBSs); and Part III relates to the players: individuals, banks, hedge funds, and private equity.

The main premise is that all financial markets are organized in the same way. All have spot (cash) transactions, forward/futures transactions and options, as well as complex swap arrangements combining all three. If you master the spot-futures cash-and-carry trade in one market (stock index arbitrage), then you can easily grasp it in another (currency-covered interest parity). If you master how delta or vega risk is hedged in equity markets, then you are likely to understand the same process in commodities or interest rates. Building a fire station with red Lego blocks is similar to building a space ship with green and blue blocks. Instead of focusing on the purpose of individual financial markets, the book focuses on the common structure. What we are building is an arbitrage or a relative value trade to profit from the real or perceived mispricing of risk. The blocks we use have the same shape, only a different color.

The building clusters in all structured products and strategies are: spot and futures trading mechanics, spot-futures linkages, option pricing, option linkages to futures, and spot, swaps, and their decomposition into bonds and forwards. The improvements in Part I consist of new chapters and easier-to-follow number and flow diagram presentations. The options discussion is split into two: options on price variables (equities, currencies, etc.) and options on non-price variables (interest rates). In the latter, we don't model prices directly – instead we model rates, derive the prices from the rates, then we price derivatives. The part includes a new chapter on credit derivatives. Part II introduces financial cash flow engineering. In addition to a survey of the perennially popular structured products, the mortgage section is substantially clearer and more complete; and the CDO section is entirely new. The analogy between prepayment and credit risk *tranching* should be very hard to miss. Part III is completely new and is mostly concerned with "why". Chapter 11, taking an individual investor perspective, is a repository of all-you-need-to-know about modern portfolio theory and its morph into statistical arbitrage methods, as well as fundamental equity valuation methods. Chapter 12 scratches the surface of hedge fund strategies and the new area of strategy indexes as a beta way of getting the alpha. Chapter 13 looks at the traditional asset-liability management for banks, which in many cases is still more useful than the newer voluminously analyzed VaR methods. Chapter 14 focuses mainly on private equity, but it also looks at liability/politics, constrained pension funds, endowments, and sovereign funds. While Part III does not answer all the *whys*, it hopefully illustrates the main motivations and quantitative techniques pursued by the key players in the financial markets.

I apologize for any mathematical errors, long sentences, or awkward grammar. I also apologize for using the royal "we" throughout the book.

Now, please find a comfortable chair, grab a pencil and a calculator, and enjoy!

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Purpose and Structure of Financial Markets

1.1 OVERVIEW OF FINANCIAL MARKETS

Financial markets play a major role in allocating excess savings to businesses in the economy. This desirable process takes various forms. Commercial banks take depositors' money and lend it to manufacturers, service firms, or home buyers who finance new construction or improvements. Investment banks bring to market equity and debt offerings of newly formed or expanding corporations. Governments issue short- and long-term bonds to finance the construction of new roads, schools, and transportation networks. Investors (bank depositors and securities buyers) supply their funds in order to shift their consumption into the future by earning interest, dividends, and capital gains.

The process of transferring savings into investment involves various participants: individuals, pension and mutual funds, banks, governments, insurance companies, industrial corporations, stock exchanges, over-the-counter (OTC) dealer networks, and others. All these agents can, at different times, serve as demanders and suppliers of funds, or as intermediaries. Economic theorists ponder the optimal design of securities and institutions, where "optimal" implies the best outcomes – lowest cost, least disputes, fastest – for security issuers and investors, as well as for the society as a whole. Are stocks, bonds, or mortgage-backed securities, the outcomes of optimal design or happenstance? Do we need "greedy" investment bankers, securities dealers, or brokers? What role do financial exchanges play in today's economy? Why do developing nations strive to establish stock exchanges even though they often have no stocks to trade on them? Once we answer these basic questions, it will not be difficult to see why all the financial markets are organically the same. In product markets, the four-cycle radiator-cooled engine-powered car and the RAM memory-bus-hard disk personal computer have withstood the test of time. And so has the spot–futures–options, primary–secondary, risk transfer-driven design of the financial market. In the wake of the 2008 crisis we have seen very limited tweaks to the design, because it is so robust.

All markets have two separate segments: *original issue* and *resale*. These are characterized by different buyers, sellers, and different intermediaries, and they perform different timing functions. The first transfers capital from the suppliers of funds (investors) to the demanders of capital (businesses); the second transfers capital from the suppliers of capital (investors) to other suppliers of capital (investors). The two segments are:

- *Primary markets* (issuer-to-investor transactions with investment banks as intermediaries in the securities markets, and banks, insurance companies and others in the loan markets);
- *Secondary markets* (investor-to-investor transactions with broker-dealers and exchanges as intermediaries in the securities markets, and mostly banks in the loan markets).

All markets have the originators, or issuers, of the claims traded in them (the original demanders of funds) and two distinctive groups of agents operating as investors, or suppliers of funds. The two groups of funds suppliers have completely divergent motives. The first group aims to eliminate the undesirable risks of the traded assets and earn money on repackaging, the other actively seeks to take on those risks in exchange for uncertain compensation. The two groups are:

- *Hedgers* (dealers who aim to offset primary risks, be left with short-term or secondary risks, and earn spread from dealing);
- *Speculators* (investors who hold positions for longer periods without simultaneously holding positions which offset primary risks).

The claims traded in all financial markets can be delivered in three ways. The first is an immediate exchange of an asset for cash. The second is an agreement on the price to be paid with the exchange taking place at a predetermined time in the future. The last is a delivery in the future, contingent upon an outcome of a financial event, e.g. level of stock price or interest rate, with a fee paid up front for the right of delivery. The three market segments based on the delivery type are:

- *Spot* or *cash markets* (immediate delivery)
- *Forward markets* (mandatory future delivery or settlement)
- *Options markets* (contingent future delivery or settlement)

We focus on these structural distinctions to bring out the fact that all markets not only transfer funds from suppliers to users, but they also transfer risk from users to suppliers. They allow *risk transfer* or *risk sharing* between investors. The majority of the trading activity in today's market is motivated by risk transfer with the acquirer of risk receiving some form of certain or contingent compensation. The relative price of risk in the market is governed by a web of relatively simple arbitrage relationships that link all the markets. These allow market participants to assess instantaneously the relative attractiveness of various investments within each market segment or across all of them. Understanding these relationships is mandatory for anyone trying to make sense of the vast and complex web of today's markets.

1.2 RISK SHARING

All financial contracts, whether in the form of securities or not, can be viewed as bundles, or packages of unit payoff claims (mini-contracts), each for a specific date in the future and a specific set of outcomes. In financial economics, these are called *state-contingent claims*.

Let us start with the simplest illustration: an insurance contract. A 1-year life insurance policy promising to pay $1,000,000 in the event of the insured's death can be viewed as a package of 12 monthly claims (lottery tickets), each paying $1,000,000 if the holder dies during that month. The value of the policy up front (the premium) is equal to the sum of the values of all the individual tickets. As the holder of the policy goes through the year, he can discard tickets that did not pay off, and the value of the policy to him diminishes until it reaches zero at the end of the coverage period.

Let us apply the concept of state-contingent claims to known securities. Suppose you buy one share of XYZ SA stock currently trading at €45 per share and pays no dividends. You intend to hold the share for 2 years. To simplify things, we assume that the stock trades once a month and in increments of €1. The minimum price is €0 (a limited liability company cannot have a negative value) and the maximum price is €199. The share of XYZ SA can be viewed as a package of claims. Each claim represents a contingent cash flow from selling the share

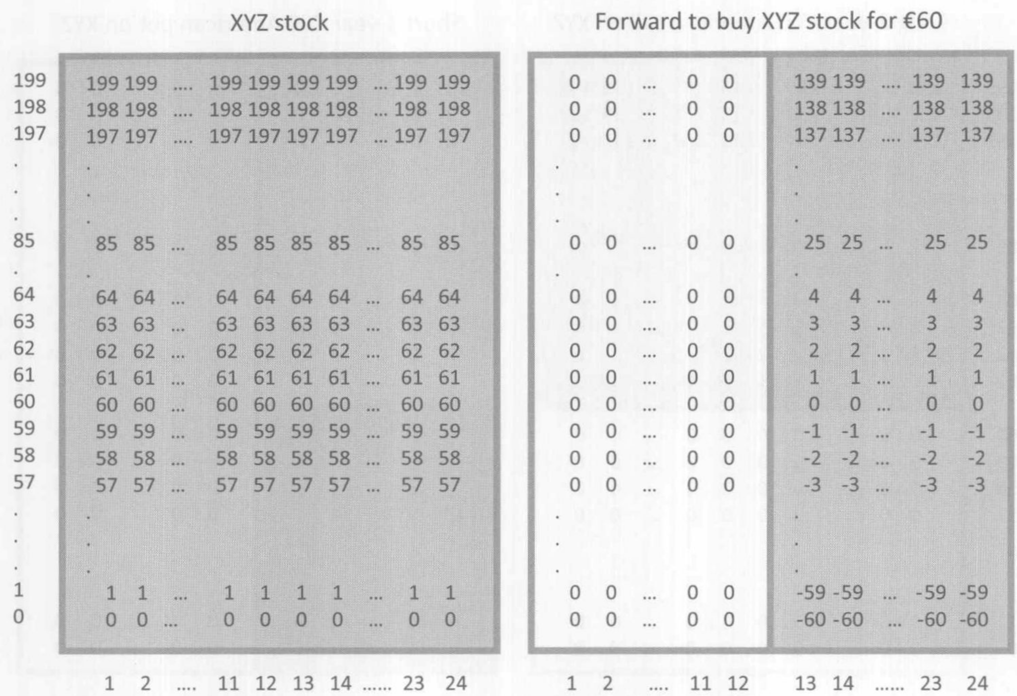

Figure 1.1 Stock and forward as packages of state-contingent claims

for a particular price in a particular month in the future. Only one of those claims will ever pay, say when we sell the stock for €78 in month 16. We can arrange the potential price levels from €0 to €199 in increments of €1 to have overall 200 possible price levels. We arrange the dates from today to 24 months from today (our holding horizon). The stock is equivalent to 200 times 24, or 480 claims. The easiest way to imagine this set of claims is as a rectangle with time on the horizontal axis and potential stock prices (states of nature) on the vertical axis. The *price* of the stock today is equal to the sum of the *values* of all the claims, i.e. all the state- and time-indexed squares of the rectangle.

Figure 1.1 shows the stock as a rectangle of 480 state-contingent claims. It also shows a forward contract on XYZ SA's stock viewed as a subset of this rectangle. Suppose we enter into a contract today to purchase the stock 13 months from today for €60. The forward can be viewed as a 200-by-24 rectangle with the first 12 months' worth of claims taken out (equal to zero, as no action can be taken). If, in month 13, the stock trades above €60, we have a gain; if the stock trades below €60, we have a loss equal to the difference between the actual stock price and the precontracted forward price.

Figure 1.2 shows a long American call option contract to buy XYZ SA's shares for €60 with an expiry 2 years from today as a 139×24 subset of our original rectangle, the rest zeroed out. The squares corresponding to the stock prices of €60 or below are eliminated, because they have no value. The payoff of each claim is equal to the intrinsic (exercise) value of the call. Figure 1.2 also shows a short American put struck at €60 with an expiry in 12 months.

The fundamental tenet of the option valuation methodology which applies to all securities is that if we can value each claim (one square of the rectangle) or small sets of claims (sections of the rectangle) in the package, then we can value the package as a whole sum of its parts.

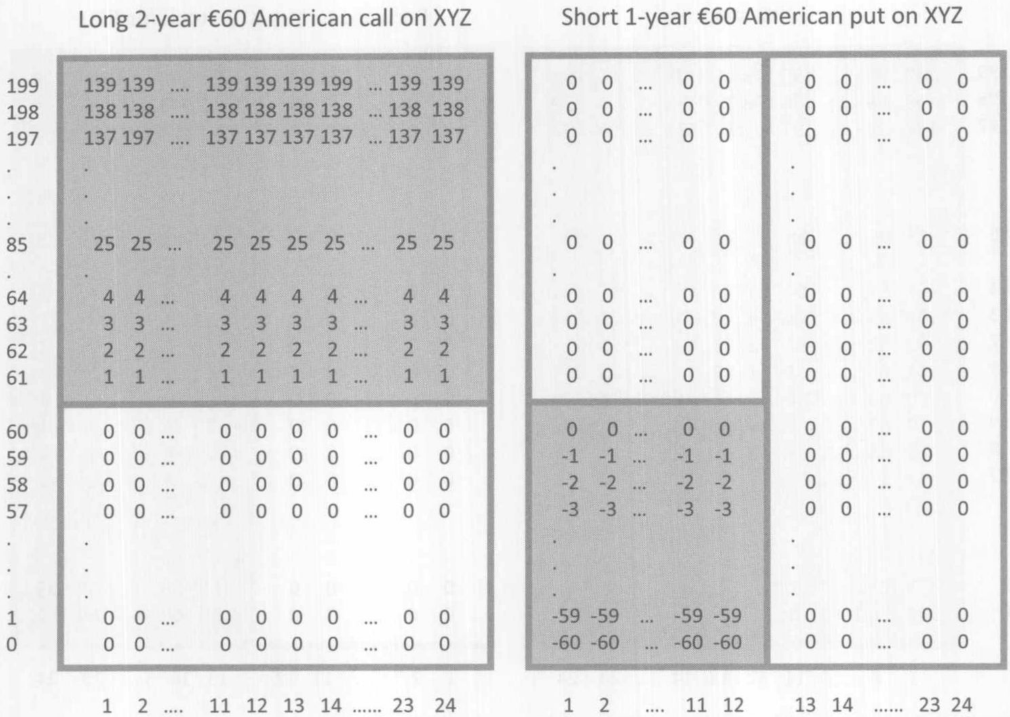

Figure 1.2 Long American call and short American put as packages of state-contingent claims.**aims**

Conversely, if we can value the package, then we are able to value subsets of claims through a subtraction of the whole minus a complement subset. Also, we may be able to combine disparate (dependent on different state variables) sets of claims (stocks on equity prices and bonds on interest rates) to form complex securities (a convertible bond). By subtracting one part (option) from the value of the combination (convertible bond), we can infer the value of a subset (straight bullet bond).

In general, the value of a contingent claim does not stay constant over time. If the holder of the life insurance becomes sick during the year and the likelihood of his death increases, then the value of all claims increases. In our stock example, the prices of the claims change as information about the company's earnings reaches the market. Not all the claims in the package have to change in value by the same amount, however. An improvement in the earnings may be only short term. The policyholder's likelihood of death may increase for the days immediately following his illness, but be less for more distant dates. As the prices of the individual claims fluctuate over time, so does the value of the entire bundle. However, at any given moment of time, the sum of the values of the claims must be equal to the value of the package, the insurance policy, or the stock. The valuation effort is restricted to here and now, and we have to repeat the exercise an instant later.

A good valuation model strives to make the claims in a package independent of each other. In our example, the payoff of the life insurance policy depends on the person *dying* during the month, not on whether the person is dead or alive. In that set-up, at most one claim of the whole set will pay. If we modeled the payoff to depend on being dead and not dying, all the claims after the morbid event would have positive prices and be contingent on each