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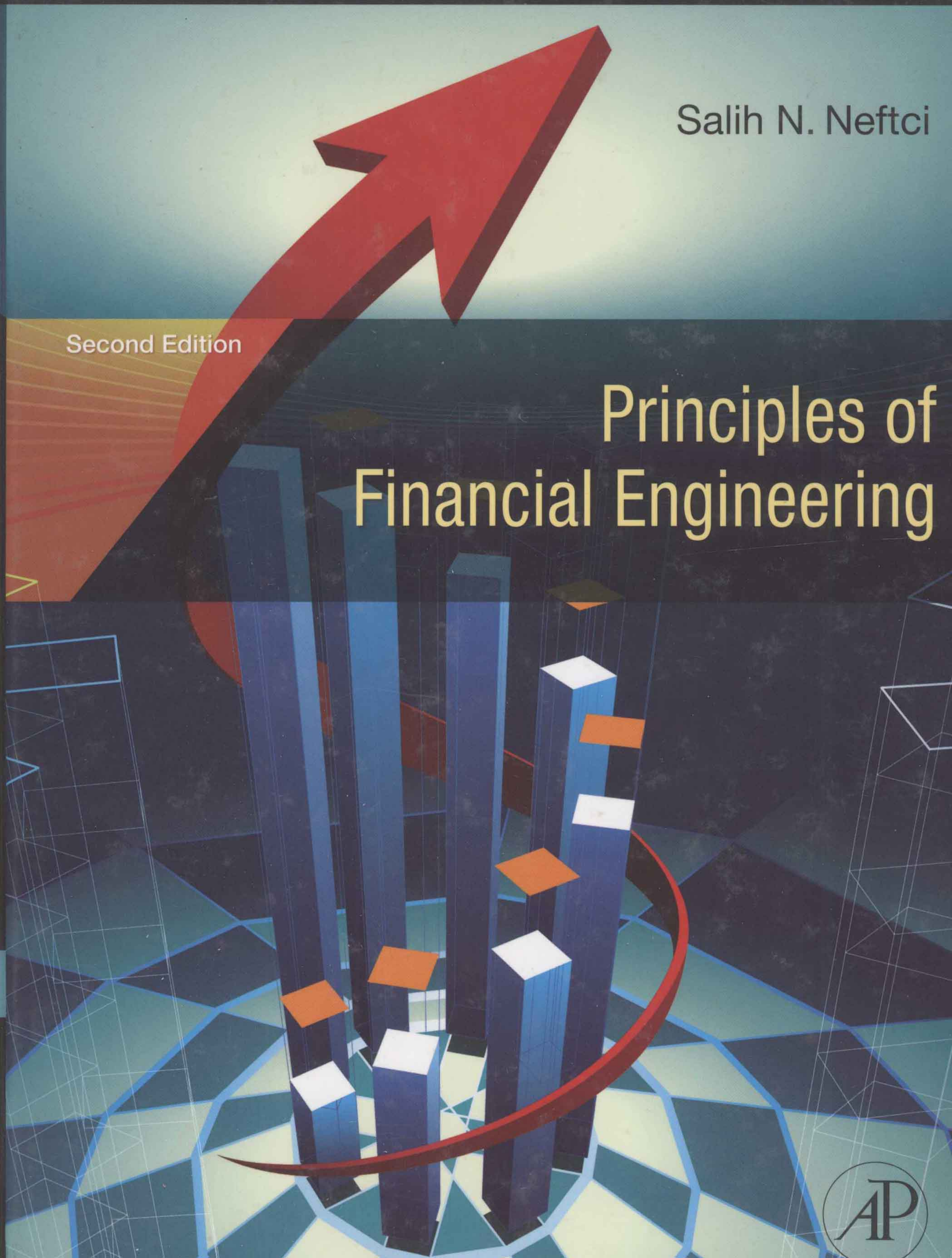
Salih N. Neftci

Second Edition

Principles of Financial Engineering



PRINCIPLES OF FINANCIAL ENGINEERING

Second Edition

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Principles of Financial Engineering

Dedicated to the following finance professionals of the future:

Emre Neftci,
Merve Neftci,
Kaya Neftci, and
Kaan Neftci.

And, of course, to the wonderful memories of my son, Oguz Neftci.

Preface

This book is an introduction. It deals with a broad array of topics that fit together through a certain logic that we generally call *Financial Engineering.* The book is intended for beginning graduate students and practitioners in financial markets. The approach uses a combination of simple graphs, elementary mathematics and real world examples. The discussion concerning details of instruments, markets and financial market practices is somewhat limited. The pricing issue is treated in an informal way, using simple examples. In contrast, the engineering dimension of the topics under consideration is emphasized.

I learned a great deal from technically oriented market practitioners who, over the years, have taken my courses. The deep knowledge and the professionalism of these brilliant market professionals contributed significantly to putting this text together. I also benefited greatly from my conversations with Marek Musiela on various topics included in the book. Several colleagues and students read the original manuscript. I especially thank Jiang Yi, Lu Yinqui, Andrea Lange, Lucas Bernard, Inas Reshad, and several anonymous referees who read the manuscript and provided comments. The book uses several real-life episodes as examples from market practices. I would like to thank International Financing Review (IFR) and Derivatives Week for their kind permission to use the material.

All the remaining errors are, of course, mine. The errata for the book and other related material will be posted on the Web site *www.neftci.com* and will be updated periodically. A great deal of effort went into producing this book. Several more advanced issues that I could have treated had to be omitted, and I intend to include these in the future editions. The future editions will also update the real-life episodes used throughout the text.

Salih N. Neftci
September 2, 2008
New York

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CHAPTER 1

Introduction

Market professionals and investors take long and short positions on *elementary assets* such as *stocks, default-free* bonds and debt instruments that carry a *default* risk. There is also a great deal of interest in trading currencies, commodities, and, recently, volatility. Looking from the outside, an observer may think that these trades are done overwhelmingly by buying and selling the asset in question *outright*, for example by paying "cash" and buying a U.S.-Treasury bond. This is wrong. It turns out that most of the *financial* objectives can be reached in a much more convenient fashion by going through a proper *swap*. There is an important logic behind this and we choose this as the first principle to illustrate in this introductory chapter.

1. A Unique Instrument

First, we would like to introduce the equivalent of the integer *zero*, in finance. Remember the property of zero in algebra. Adding (subtracting) zero to any other real number leaves this number the same. There is a unique financial instrument that has the same property with respect to market and credit risk. Consider the cash flow diagram in Figure 1-1. Here, the time is continuous and the t_0, t_1, t_2 represent some specific dates. Initially we place ourselves at time t_0. The following deal is struck with a bank. At time t_1 we borrow USD100, at the *going* interest rate of time t_1, called the *Libor* and denoted by the symbol L_{t_1}. We pay the interest and the principal back at time t_2. The loan has no default risk and is for a period of δ units of time.[1] Note that the contract is written at time t_0, but starts at the future date t_1. Hence this is an example of *forward* contracts. The actual value of L_{t_1} will also be determined at the future date t_1.

Now, consider the time interval from t_0 to t_1, expressed as $t \in [t_0, t_1]$. At *any* time during this interval, what can we say about the value of this forward contract initiated at t_0?

It turns out that this contract will have a value *identically* equal to zero for all $t \in [t_0, t_1]$ regardless of what happens in world financial markets. Perceptions of future interest rate

[1] The δ is measured in proportion to a year. For example, assuming that a "year" is 360 days and a "month" is always 30 days, a 3-month loan will give $\delta = \frac{1}{4}$.

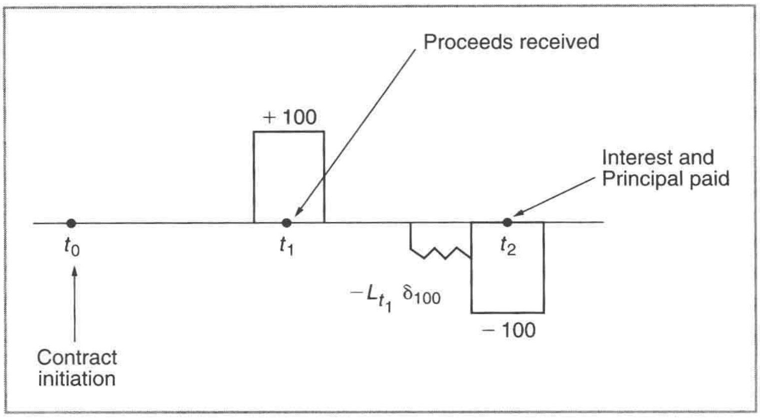

FIGURE 1-1

movements may go from zero to infinity, but the value of the contract will still remain zero. In order to prove this assertion, we calculate the value of the contract at time t_0. Actually, the value is obvious in one sense. Look at Figure 1-1. No cash changes hand at time t_0. So, the value of the contract at time t_0 must be zero. This may be obvious but let us show it formally.

To value the cash flows in Figure 1-1, we will calculate the time t_1-value of the cash flows that will be exchanged at time t_2. This can be done by discounting them with the *proper* discount factor. The best discounting is done using the L_{t_1} itself, although at time t_0 the value of this Libor rate is not known. Still, the time t_1 value of the future cash flows are

$$PV_{t_1} = \frac{L_{t_1}\delta 100}{(1 + L_{t_1}\delta)} + \frac{100}{(1 + L_{t_1}\delta)} \tag{1}$$

At first sight it seems we would need an estimate of the random variable L_{t_1} to obtain a numerical answer from this formula. In fact some market practitioners may suggest using the corresponding *forward rate* that is observed at time t_0 in lieu of L_{t_1}, for example. But a closer look suggests a much better alternative. Collecting the terms in the numerator

$$PV_{t_1} = \frac{(1 + L_{t_1}\delta)100}{(1 + L_{t_1}\delta)} \tag{2}$$

the unknown terms cancel out and we obtain:

$$PV_{t_1} = 100 \tag{3}$$

This looks like a trivial result, but consider what it means. In order to calculate the value of the cash flows shown in Figure 1-1, we don't *need* to know L_{t_1}. Regardless of what happens to interest rate expectations and regardless of market volatility, the value of these cash flows, and hence the value of this contract, is *always* equal to *zero* for *any* $t \in [t_0, t_1]$. In other words, the *price volatility* of this instrument is identically equal to zero.

This means that given any instrument at time t, we can add (or subtract) the Libor loan to it, and the value of the original instrument will *not* change for all $t \in [t_0, t_1]$. We now apply this simple idea to a number of basic operations in financial markets.

1.1. Buying a Default-Free Bond

For many of the operations they need, market practitioners do not "buy" or "sell" bonds. There is a much more convenient way of doing business.

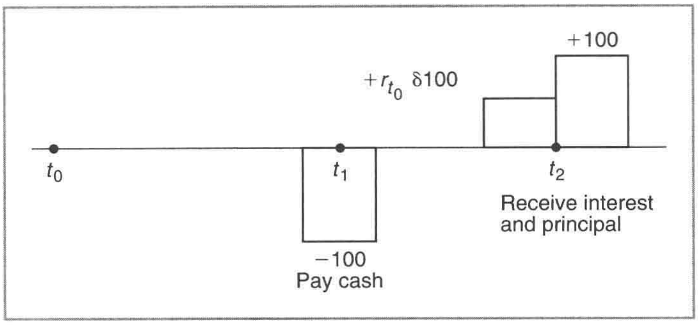

FIGURE 1-2. Buying default-free bond.

The cash flows of buying a default-free coupon bond with par value 100 *forward* are shown in Figure 1-2. The coupon rate, set at time t_0, is r_{t_0}. The price is USD100, hence this is a *par bond* and the maturity date is t_2. Note that this implies the following equality:

$$100 = \frac{r_{t_0}\delta 100}{(1 + r_{t_0}\delta)} + \frac{100}{(1 + r_{t_0}\delta)} \tag{4}$$

which is true, because at t_0, the buyer is paying USD100 for the cash flows shown in Figure 1-2.

Buying (selling) such a bond is inconvenient in many respects. First, one needs cash to do this. Practitioners call this *funding*, in case the bond is purchased. When the bond is sold short it will generate new cash and this must be managed.[2] Hence, such outright sales and purchases require inconvenient and costly *cash management*.

Second, the security in question may be a *registered* bond, instead of being a *bearer* bond, whereas the buyer may prefer to stay anonymous.

Third, buying (selling) the bond will affect *balance sheets*, called *books* in the industry. Suppose the practitioner borrows USD100 and buys the bond. Both the asset and the liability sides of the balance sheet are now larger. This may have *regulatory* implications.[3]

Finally, by securing the funding, the practitioner is getting a loan. Loans involve *credit risk*. The loan counterparty may want to factor a default risk premium into the interest rate.[4]

Now consider the following operation. The bond in question is a contract. To this contract "add" the forward Libor loan that we discussed in the previous section. This is shown in Figure 1-3a. As we already proved, for all $t \in [t_0, t_1]$, the value of the Libor loan is identically equal to zero. Hence, this operation is similar to adding *zero* to a risky contract. This addition does not change the *market* risk characteristics of the original position in any way. On the other hand, as Figure 1-3a and 1-3b show, the resulting cash flows are significantly more convenient than the original bond.

The cash flows require *no upfront* cash, they do not involve buying a *registered* security, and the *balance sheet* is not affected in any way. Yet, the cash flows shown in Figure 1-3 have *exactly* the same market risk characteristics as the original bond.

Since the cash flows generated by the bond and the Libor loan in Figure 1-3 accomplish the same market risk objectives as the original bond transaction, then why not package them as a *separate* instrument and market them to clients under a different name? This is an Interest Rate

2 Short selling involves *borrowing* the bond and then selling it. Hence, there will be a cash management issue.

3 For example, this was an emerging market or corporate bond, the bank would be required to hold additional capital against this purchase.

4 If the Treasury security being purchased is left as collateral, then this credit risk aspect mostly disappears.