AN INTRODUCTION TO ALGORITHMIC FINANCE, ALGORITHMIC TRADING AND BLOCKCHAIN

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INVESTOR IN PEOPLE

Satya R. Chakravarty dedicates this book to his granddaughter,
Anvi Ananyo Chakravarty (Gini).
Palash *Sarkar dedicates this book to his mother.*

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Preface

Our motivation for writing this book is to provide a broad-based and accessible introduction to three of the presently most important areas of computational finance, namely, option pricing, algorithmic trading and blockchain. To the best of our knowledge, no other book in the market provides such a coverage. It is our hope that the book will be useful to senior undergraduates, graduates and MBA students, as well as researchers and practitioners. In its first part, the book reflects option pricing in different frameworks. A simple treatment of assessment of cash flows and fixed security derivatives is also presented. Finally, the problem of asset ranking is addressed in this part of the book. In a broad sense, the second part of the book covers algorithmic issues related to finance. The first three chapters of the second part addresses some computational issues related to the theory discussed in the first part. The rest of the second part, consisting of five chapters, discusses approaches for algorithmic trading, portfolio optimisation and risk management. The third part of the book is devoted to blockchain and cryptocurrency. A fairly detailed introduction to both of these topics is presented along with various applications of blockchain to financial and other applications. The wide coverage of the book and its authentic and well-expressive presentation make the book quite up-to-date from both theoretical and practical sides, and highly reactive to the problems of recent concern. We believe that in satisfying its objectives, our book offers a unique perspective to contemporary aspects of finance in a lucid manner for senior undergraduates, graduates, MBA students and regulators. Further, the book can serve as a useful reference for basic theory to practitioners in the area. Much of finance today involves a fair amount of mathematics. In the book, we have tried to find a balance between having too much and too little mathematics. Detailed mathematical derivations have been given in some cases, helpful aids have been provided in some other cases so that a reader can complete the derivations, and for cases where the proofs takes us too far away from the discussion at hand, the proofs have been omitted. In our opinion, the first two parts of the book can be understood by somebody having a college-level introduction to calculus, linear algebra, probability and statistics. The mathematical requirement for the third part is markedly different from that of the first two parts. It is due to this reason we have tried to keep the mathematical description of the third part to a bare minimum. Several chapters of the book have been used for offering a course on the theory of finance to Master of Science in Quantitative Economics students at the Indian Statistical Institute, Kolkata, India, in the Fall Semester of 2019. The materials were well received by the students. We express our sincere gratitude to the students for their enthusiasm and helpful comments in the process of direct interactions. We thank Pinaki Sarkar for providing several suggestions to improve the coverage of the book. We also thank Sanjay Bhattacherjee for reading and commenting on some chapters of the third part.

Satya R. Chakravarty and Palash Sarkar
Kolkata, India
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Part I
Derivatives, Options and Stochastic Dominance

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Chapter 1

Background and Preliminaries

The financial industry is enormously important to state, national and world economies. This industry relies extensively on mathematical modeling of underlying instruments. Computational techniques become helpful in designing related algorithms that enable us to understand how markets function and also lend themselves to highly relevant research problems.

To understand the application of a specific computational technique to the particular financial instrument, it becomes indispensable to have a clear perception of the underlying theory. However, because of vastness of the theoretical literature, some selection becomes necessary.

We choose the highly attractive field of option pricing, a core task of computational finance and risk analysis. An option is a contract that gives the holder the right, but not an obligation, to buy or sell an asset at a pre-agreed price, the strike price, on or before the date of expiry, the maturity date. The broad field of option pricing is quite ambitious and diverse enough to call for a wide range of computational tools. Confining mostly to option pricing enables us to have a more coherent and comprehensive textbook, to a large extent, and avoids being distracted away from computational issues. An option is a standard example of a derivative, a financial instrument whose value relies on one or more assets that are usually referred to as underlying assets. Generally, it takes the form of a contract to buy or sell an asset or item like commodity, property, etc. at the strike price, on or before the expiration date. Other examples of a derivative include bonds, futures contracts, forward contracts and swaps. (For detailed discussions see, among others, Jarrow and Turnbull, 2000.) The financial market in which derivatives are traded may be designated as the derivatives market. We assume a perfect market in the sense that there are no costs of transactions, no restrictions on short sales and existence of a common borrowing and lending rate. Short selling is a business tactic that involves borrowing an asset and selling it immediately, repurchasing the asset (hopefully at a lower price) and returning it to the lender to close the process. (Chapters 11 and 15 of this monograph provide further discussions along this line.)

A derivatives market can be partitioned into two subgroups, one in which derivatives are traded in an organised exchange market where maintenance of market price and all transparencies are provided. An example of an exchange-traded derivative is an option. Under a futures contract, an exchange-traded

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agreement, the buyer is accountable to buy the underlying asset at a pre-arranged price at a future date. The seller makes the commitment to hand over the asset at the settled price and date. Another market-traded derivative is a bond, a debt security issued by government and corporate sectors to raise funds for various purposes including expansion of one or more sectors, infrastructural improvements and payment of existing debts. A financial market in which trading of bonds takes place is known as a bond or credit or debt market. A trading in the other market is of over-the-counter (OTC) type. This type of off exchange trading takes place directly between the traders without supervision of an exchange. An example of an OTC derivative is a forward contract under which two parties make an agreement to buy or sell an asset at a designated date on a promised price. A swap is an off exchange-traded derivative under which a financial instrument is exchanged between the parties concerned at a pre-specified time.

A highly significant component of the derivatives market is risk. Risks can be of various types such as asset risk, interest rate risk, foreign exchange risk, credit risk, commodity risk and so on. While asset risk arises from volatility in asset prices, interest rate risk refers to the chance that variations in rate of interest may negatively affect an investment. Likewise, foreign exchange risk emerges from fluctuations in exchange rate between two different currencies. On the other hand, credit risk indicates the possibility of a lender's loss of principal and interest if a borrower fails to make committed payments. Commodity risk is related to the apprehension of loss that may arise because of oscillation in a commodity price in the future. But risks may also bring about unexpected benefit. Investors wish to make risky investments with the expectation of making profits in the future. Given that there can be alternative notions of risk, use of appropriate tools for the purpose of risk management becomes essential. Different forms of derivatives become useful in this situation. More precisely, derivatives are financial instruments for administering financial risks. They transfer different forms of financial risks to derivatives market. They are financial securities for hedging or bordering risks in the sense of protecting or at least reducing risks. The basic principle underlying asset pricing is the existence of non-arbitrage. According to an arbitrage opportunity, a trader can take advantage of price imbalance to extract rapid profit without any risk. Consequently, the non-arbitrage assumption means the rule of a single price. (Further discussions on arbitrage are available in Chapters 11 and 15 of this monograph.)

Since in the first part of the monograph we will be mainly concerned with options, a brief, rigorous and authoritative discussion on options and related phenomena is presented in Chapters 3–6. For the sake of completeness, an abridged analysis of valuation of cash flows and fixed income securities is presented in Chapter 2.

Given that any investment in a risky asset includes the chance of a loss, it is quite likely that an investor will look into the problem of risk management in a portfolio, a composition of assets held by the investor. The investor often may be confronted with the necessity of ordering distributions of random returns on various financial assets or combinations of them on the basis of his preferences, represented by a von Neumann–Morgenstern utility function. This issue has been addressed in several pioneering contributions to the literature. A quite general approach to the resolution of the problem is the rule of stochastic dominance that enables us to order the distributions of random rates of return on assets for large classes of utility functions. No specific knowledge about the form of utility function is necessary. A concise illustrative introduction to the concept of stochastic dominance is presented in Chapter 7.

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Chapter 2

Valuation of Cash Flows and Fixed Income Securities: An Abridged Analysis

2.1 Introduction

In order to judge profitability of an investment, say, a firm's investment in a project, it becomes necessary to compare present values of cash inflows (benefits) and outflows (costs). The net present value (NPV) criterion that looks at the difference between present values of benefits and costs is a standard tool for this type of analysis. Alternatives to this are benefit–cost ratio and internal rate of return (IRR), a discount rate that makes NPV equal to zero. In this chapter, we present a brief discussion on these criteria. A brief discussion on bond as a particular type of constant earning security is also presented.

2.2 Net Present Value

When a firm has decided to start a project, this decision will have some important implications on the firm's financial position for one or more periods. The firm has to obtain an overall indicator that will judge whether it will become better off or worse off when the project has been undertaken.

The NPV method, which is employed to determine current values of all inflows and outflows associated with an investment, is an appropriate tool for this purpose. The risk-free interest rate r over the lifespan of the project is assumed to remain constant.

We denote money inflows (benefits) and outflows (costs) occurring in period t by B_t and C_t, respectively, where $t = 0,1\ldots,T$. Here, $t = 0$ and $t = T$ represent, respectively, the current period and final period for which the investment affects benefits and costs. While C_0 indicates the size of the initial investment, for $t \geq 1$, C_t may be regarded as the maintenance cost. It is natural to assume that $C_0 > 0$ and $C_t \geq 0$ for $t \geq 1$. On the other hand, B_0 is likely to be 0, but from $t = 1$ onwards, B_ts are non-negative. Then the discounted present value (DPV) of the inflows

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comes to be $\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}$. Similarly, the DPV of the outflows becomes $\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$. Then the NPV of the project can now be defined as

$$\text{NPV} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t}. \tag{2.1}$$

The project should be undertaken or rejected according as NPV $>$ 0 or NPV $<$ 0. The firm is indifferent between the two options if NPV $=$ 0. For NPV to be an appropriate guideline for launching a new project, it becomes necessary to get correct estimates of B_t and C_t in different periods. If investment amounts differ across projects, then the NPV criterion cannot be used to compare them. Also the lifespan of the projects have to be the same for the purpose of comparison.

A firm can also use the benefit–cost ratio as a yardstick to judge whether a project should be undertaken or not. It is formally defined as

$$\frac{B}{C} = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}. \tag{2.2}$$

Evidently, B/C is greater or less than 1 if and only if the NPV is positive or negative. Higher values of both the criteria NPV and B/C are better for the investor. However, they may rank alternative projects in different directions.

The final evaluator we use in the current context is the IRR, the rate of interest rate that makes the NPV of the project equal to 0. Since interest rate can be interpreted as time value of money, IRR is the interest rate that an investor can expect from his investment. If IRR is higher than the rate of discounting then the project should be undertaken. IRR can be implicitly defined as

$$\sum_{t=0}^{T} \frac{B_t - C_t}{(1+\text{IRR})^t} = 0. \tag{2.3}$$

In general, there are T roots of this equation. In such a case, the highest root whose value exceeds the discount rate may be used as IRR. In case there are mutually several exclusive projects, then the firm should choose the one that produces the highest IRR. When the discount rate varies over time, the use of the IRR criterion as an evaluation principle for selection of a project may not be feasible. Thus, while the concern of NPV is project surplus, IRR is concerned with break-even money flow. Of these two criteria, NPV is more popular as a project selection yardstick because it is easy to understand in terms of profitability of a project. (For further discussions, see Bierwag, 1987 and Damodaran, 2010.)