Preface

This volume is a collection of research contributions to applied problems in finance and energy which are formulated and solved in the framework of stochastic optimization. The invited authors represent a group of academics and practitioners who have facilitated the growing penetration of stochastic programming techniques into real-world applications in recent years. Their present contributions represent significant advances over a large spectrum of complex decision problems.

As a result of the recent widespread liberalization of the energy sector in Europe and the unprecedented growth of energy prices in international commodity markets, we have witnessed a significant convergence of strategic decision problems in the energy and financial sectors. This has resulted in many common open issues, calling forth a remarkable effort by the industrial and scholarly communities to forward the practical use of advanced analytical and decision tools. The main concerns of the financial community over the past decade have suddenly been taken up by the energy sector in addressing previously intractable management problems.

This volume includes for the first time in a unified framework an extensive set of contributions addressing real-world problems in finance and energy in a common methodological framework. In many cases the chapters have similar underlying economic and financial assumptions.

During the spring and the summer of 2007, the School of Stochastic Programming held in Bergamo (www.unibg.it/sps2007) and the eleventh International Symposium on Stochastic Programming held in Vienna (http://www.univie.ac.at/spxi) offered two venues for the presentation of the chapters included in the volume.

The volume is structured in three parts: devoted respectively to *financial applications* – Part I with six chapters, *energy applications* – Part II with seven chapters, and *theoretical and computational issues* – Part III with five chapters. The contributions in Part III have all been developed recently and are explicitly related to the applied problems tackled in Parts I and II.

The 13 chapters in Parts I and II address modeling and implementation issues arising in multistage stochastic programming formulations. They focus on real-world problems in finance and energy, clearly identifying common solutions and open problems. In each part the topics of individual chapters move from the general to the specific, evolving in a logical and connected order and indicating the way forward in applied stochastic optimization.

Part I: Financial Applications

Chapter 1, by Ziemba and MacLean, revisits the classical problem of capital accumulation under uncertainty which has occupied a central role in economic and financial theory over many years. The authors analyze the *actual* performance of portfolio management schemes relying on the so-called *Kelly-,* or *capital growth-,* investment strategies whose long-run asymptotic properties lead to optimal strategies for "sufficiently patient" investors. The *optimality* of the Kelly strategy is related to expected values of either long-run wealth or first passage times. In the presence of probabilistic security constraints the problem of maximizing the rate of growth of wealth leads to nonconvex optimization problems which are difficult to solve. After reviewing the key theoretical results regarding the adoption of complete or partial Kelly strategies, the authors present an alternative solution approach based on the introduction of a convex penalty on violations of portfolio drawdown conditions and they analyze the comparative performance of different modeling approaches for a long-term equity investor.

Chapter 2, by Dempster et al., addresses from a large institutional investor's perspective the provision of *guaranteed investment products* for *defined contribution pension savings plans.* These latter have recently been forced on individual households by governments and corporations, respectively, withdrawing pay-as-you-go public and funded defined benefit pension schemes as financially unsustainable. The popularity of such products has increased as investors rightly worry about the downside potential of financial markets. This chapter introduces a simplified dynamic stochastic optimization model for the design and risk management of closed end funds backing guaranteed investment products which underlay that actually used to manage the open-ended funds backing more complex products. The authors describe in detail the pricing of minimum guarantees as well as the valuation of a portfolio of bonds using a three-factor term structure model. Upside for the investor is provided by the equity component of the portfolio. Back tests through the Internet bubble and crash show that effective upside provision and downside risk management can be improved by evaluating risk in the model at a higher frequency than portfolio rebalancing and by modeling equity indices with a (downside) asymmetric jump process.

Chapter 3, by Mulvey et al., considers the problem of institutional investors optimally managing their global portfolios funding *defined benefit (DB) pension plans* through the use of dynamic long–short *duration enhancing overlay* strategies involving equal value positions in long treasury bonds and short treasury bills in order to protect asset wealth and surplus through periods of poor market performance. The proposed overlay strategies do not require capital but must be tightly risk managed. In light of the serious underfunding of DB schemes at present and after the previous Internet bubble and crash, wealth protection has become a critical problem on both sides of the Atlantic. A multistage stochastic program provides the ideal setup for constructing an adaptive dynamic optimal DB investment portfolio and the authors also consider the approximation of its optimal recommendations by derived decision rules. Several illustrative examples are presented in the chapter and the performance of the recommended strategies is evaluated by both back tests and a forward-looking ALM system.

Chapter 4, by Beraldi et al., discusses the problem of dynamically *hedging* a portfolio exposed to *interest rate and default risk* in an integrated manner. No overlays are considered in this case, but rather the potential of a stochastic programming formulation for indirect hedging is tested on a large-scale corporate portfolio. The effectiveness of the multistage strategy is evaluated through the recent 2008–2009 credit crisis, which has provided an ideal stressed period for bond portfolio managers worldwide. It is shown that the dynamic stochastic optimization framework provides an effective alternative to hedging using credit derivatives throughout a period when credit derivative markets became highly illiquid.

Chapter 5, by Consigli et al., describes a case study developed in conjunction with a large global *property and casualty insurer* preparing for the implementation of the EU Solvency II regulations on insurance companies. The chapter develops a *multi-objective* (over short-, medium-, and long-term horizons) dynamic stochastic programming ALM model for the management of an investment portfolio subject to premium inflows and catastrophic claim outflows. As opposed to current practice, the chapter stresses the benefits of a dynamic stochastic ALM formulation of the problem and investigates its performance in a *stressed claim liability* scenario. The reported results serve as a basis for further work in this important area.

Chapter 6, by Consiglio and De Giovanni, concerns *reinsurance contracts*. Optimal portfolio management by pension funds with minimum guarantees combines the optimal tracking and the option valuation problems in a unique, often complex, mathematical framework. Similarly, reinsurance products are usually equipped with *minimum and maximum guarantees* and *surrender options* and their pricing is vital for the insurance industry. In the discrete time, discrete state framework used by stochastic programming formulations the optimal payoff replication problem translates into an option valuation problem in *incomplete markets*. Risk management, strategic asset allocation, and product design depend on the correct evaluation of these contingent claims. To overcome Black and Scholes complete market limitations, the authors have developed a stochastic programming *super-hedging* model to determine the fair price of reinsurance contract provisions. An extensive empirical analysis is presented to highlight the effect of incompleteness on the fair values of the optionalities and to show how the proposed framework can be used as a valuable normative tool for insurance companies and regulators.

In summary, the six chapters of Part I move from a classical financial management problem to a set of state-of-the-art applications in finance and insurance within the dynamic stochastic programming paradigm. The key issues of a stochastic programming mathematical formulation, scenario generation for a wide set of financial management problems, risk characterization, and optimal portfolio control, are all considered. From individual (Chapter 1) to institutional (Chapters 2, 3, 4, and 5) investors, such as pension funds and insurance companies, financial management problems are presented in various case studies which provide a rich set of evidence and practical suggestions for both academia and industry.

Part II: Energy Applications

Many of the methodological issues addressed in Part I of the volume are reprised in the chapters dedicated to energy applications. The advent of liberalized energy markets has brought about an increasing need for new modeling approaches and efficient risk management tools. This has strengthened the cooperation between the scientific community and the energy industry as is reflected in the problems and case studies analyzed in this second part of the volume. The growing environmental concern related to energy sector development worldwide has also forced the adoption of new and more efficient decision support systems which take into account the implications and economic sustainability of alternative energy policies. In an optimization framework this results in additional constraints in the models of the problems treated. Unlike financial applications, where securities are held over time and investors' inter-temporal strategies rely explicitly on inventory balance constraints linking period to period, optimal policies by energy producers confronting significant market risks are often determined by taking into account the physical nature of non-storable energy. In competitive markets with a limited number of energy suppliers and state-controlled network connections, energy producers must further employ optimal supply policies which take into account competitors' behavior. These considerations add complexity to the definition and solution of stochastic optimization problems in the energy sector and are fully reflected in the chapters of Part II.

Chapter 7, by Ramos et al., formulates and solves an optimal *resource allocation* problem for *thermal and hydropower plants* with multiple basins and multiply connected reservoirs. The stochastic factors in the problem are model natural hydro inflows. A multivariate scenario tree is developed taking into account these stochastic inputs and their spatial and temporal dependencies. Hydropower plant efficiency depends in general on *water head* and *reservoir volume*. Here the dependence on water head is modeled as nonlinear, leading to a large-scale *stochastic nonlinear optimization* problem whose formulation and solution are described by the authors.

Chapter 8, by Giacometti et al., analyzes an optimal *short-term hydro-thermal coordination* problem for the case of a small *price-taking producer* seeking to maximize expected profits and reduce market risk. Day-ahead market prices and reservoir inflows are characterized by the uncertainty caused by market fluctuations and unpredictable weather conditions. A multistage stochastic programming model framework is appropriate, as in the real-world information evolves over time and uncertainties are disclosed in stages. The overall objective of the stochastic optimization problem is to establish a *one-day production plan* in order to optimally determine the trade-off between current and future expected profits subject to operational constraints.

Chapter 9, by Triki et al., considers the problem of *optimal bidding* in the *spot electricity markets* by each power producer with the aim of maximizing his profits. The multiplicity of bidding opportunities (auctions) and the limitations imposed by technical constraints and market rules make the problem difficult to model and solve. Further difficulties are represented by the dynamic and stochastic nature of the decision process. The authors focus on the use of stochastic programming to deal with the bidding problem and survey the different modeling paradigms for its formulation and the solution methods currently available for its solution.

Chapter 10, by Alonso-Ayuso et al., proposes a *multistage mixed integer full recourse model* for the similar problem for price-taking agents of *structuring energy contract portfolios* in *competitive markets*. The main uncertain parameters represent spot energy prices, water exogenous inflows to the hydrosystem, and fuel and gas costs and availabilities. The objective is given by the maximization of expected (over scenarios) bilateral and spot market trading profits along the time horizon. The problem is formulated in terms of a *mixed 0–1 deterministic equivalent* model of the stochastic problem which imposes Kyoto protocol-based *regulations for pollutant emissions*. Only 0–1 variables appear in the first stage of the constraint system and all continuous variables appear in the formulation of later stages.

Chapter 11, by Fodstad et al., introduces a comprehensive *network model* to solve a *tactical* (up to 3 years) *planning* problem in the *natural gas supply chain* of a Norwegian company. The authors present a decision support tool for a *large producer* with a portfolio of production fields and access to the transportation grid. The system takes a global view of the supply chain, including such elements as production fields, transportation pipelines, storage, bilateral contracts, and spot markets. The need for a stochastic optimization framework in this case is due to the inclusion of *bilateral contracts* in which the buyer's obligations and prices are treated as uncertain parameters. Spot energy prices are also uncertain. The goal for the producer is to allocate gas equitably and use market flexibility to ensure that delivery obligations and expected profit maximization are both attained. The authors address in an integrated way short-term expected profit maximization under long-term transportation bottleneck and other infrastructural constraints.

Chapter 12, by Drapkin et al., is devoted to a dynamic formulation of the *risk management* problem in *liberalized energy markets*. Under conditions of increasing commodity price volatility the need to address in a coherent financial framework an efficient hedging strategy is considered. The authors propose a new approach to risk management in energy optimization by employing the concept of *stochastic dominance*. This leads to a new class of large-scale block-structured mixed-integer linear programs for which the two authors present a decomposition algorithm involving *Lagrangean relaxation* and *cutting plane techniques*. This methodology is applied to stochastic optimization problems related to *operation and investment planning* in energy systems with dispersed generation.

Chapter 13, the final chapter of Part II by Ehrenmann and Smeers, analyzes probably one of the oldest applications of optimization with a long-term perspective, the *capacity expansion* problem. The solution of this problem needs to be reconsidered for the energy industry after its profound restructuring in recent years and the resulting energy price liberalization. The authors analyze the implications of optimal investment strategies within an *equilibrium model* with *risk-averse agents*. A new model paradigm is presented taking into account the endogenous nature of the cost of *investment capital*. The behavior of agents is described by a multistage risk function. They use a multistage version of the *Cochrane good deal* to obtain a risk function that has good time consistency properties and allows one to tie up their problem formulation with standard models of corporate finance such as the CAPM and APT. The problem is formulated as a *stochastic complementarity problem*. Although it has so far been impossible to establish any monotonicity property of the model, more general fixed-point theorems can be invoked to prove existence of an equilibrium. The authors' contribution appropriately links the second part of this volume with the remaining chapters which are dedicated to an important set of theoretical and computational issues.

The seven chapters of Part II provide a unique and well-integrated set of contributions which address valuation and decision problems in the energy sector after the recent policy changes in the sector. The parallels between short-term optimal dynamic portfolio policies in financial markets and optimal management of electricity contracts under energy price volatility are clear. In both cases, the need from a methodological viewpoint to combine an accurate model of uncertainty with a decision tool leading to a practical efficient decision process emphasizes the similar requirements of the corresponding decision models. The contributions in this second part of the volume move from the tactical to the strategic horizon, with increasingly relevant policy implications.

Part III: Theory and Computation

The case studies in Parts I and II of the book call for efficient approximation methods for the underlying generally continuous probability distributions associated with the stochastic nature of the decision problems, together with effective solution schemes for typically computationally intensive problems. Part III consists of five theoretical developments explicitly addressing the issues of unbiased scenario tree generation and the numerical solution of linear and nonlinear stochastic programs. The first three chapters of this part, taken together, provide an accurate assessment of the scenario generation procedures adopted in the case studies presented previously from both the theoretical and computational viewpoints. The last two chapters consider stochastic programming universal problems in, respectively, scenario generation and risk measure specification, namely, statistical dependence between risk factors and the implications of risk measures for optimal decisions. All five chapters contain a mixture of theoretical results and their computational evaluation.

Chapter 14, by Römisch and Heitsch, presents an overview of recent developments in *scenario generation* techniques for financial and energy problems. The authors analyze a set of theoretical results related to the approximation of random processes in appropriate functional spaces using *stability theory* with a view stabilizing the *small sample behavior of objective function values* of dynamic stochastic programming problems. The concepts are illustrated in the context constructing scenario trees of demand and prices for the *electricity portfolio management of a municipal power utility.*

Chapter 15, by Pflug and Pichler, continues the theme of the previous chapter. The authors first consider the basic problem of measuring the *distance between* *two multivariate probability distributions* and then apply the results to find a set of good single period scenarios before treating the corresponding multi-period problem. They conclude by addressing the important problem of generated *scenario tree reduction* which is minimally objective biased in the smaller sample tree and leads to reduced stochastic optimization problem solution times. Numerical examples are given throughout the chapter to illustrate the concepts discussed.

Chapter 16, by Dempster et al., goes a step further than its two predecessor chapters by focussing on the small sample stability of optimal *implementable* (first stage or root node) *decisions* in dynamic stochastic programming problems. This is *the* important problem in financial applications, in which the implementable decisions represent an optimal initial portfolio robust to alternative future market and liability scenarios, but one upon which little work has previously appeared. The authors propose a fast heuristic for minimizing the *Kantorovich–Wasserstein distance* between probability distributions and go on to compare its effectiveness in application to the objective and implementable decision stability of the guaranteed return fund management dynamic optimization problem of Chapter 2 with *Monte Carlo* and *moment-matched Monte Carlo* scenario generation techniques. This is a computationally intensive study which shows that *algebraic two-moment matching* is the preferred technique. An equally important finding is that much larger scenario trees than have previously been used in the practical literature are needed to remove small sample solution bias, particularly when risk is tightly constrained.

Chapter 17, by Henrion and Strugarek, establishes the convexity properties of stochastic optimization problems with *chance constraints*. The authors extend the classical theory of chance-constrained problems with *independent* random processes to the case of *codependence* modeled through *copulas*. The related theoretical results are presented and illustrated by a number of examples.

Chapter 18, the final chapter of the volume by Fabian et al., presents a theoretical and computational study of *second-order stochastic dominance* risk measures for single period portfolio choice models (cf. Chapter 12 which applies dominance concepts to control risk in the design and operation of power systems). The authors survey recent results regarding the problem addressed and then undertake an extensive computational study to investigate the effects of various risk measures on *portfolio return distributions*. They conclude that finding an acceptable portfolio strategy and then computing one which maximally dominates it is an alternative to the more usual trade-off of risk, however defined, and expected return.

This concludes a summary of the contents of this volume which we hope will be useful to both the reader and prospective reader. All in all we are proud of the collection of timely and practically relevant contributions the book represents and we hope that the reader will gain as much enjoyment and enlightenment from it as we did in compiling and editing it.

Bergamo, Italy — Marida Bertocchi
Bergamo, Italy — Giorgio Consigli
Cambridge, UK — Michael A.H. Dempster

Springer
http://www.springer.com/978-1-4419-9585-8

Stochastic Optimization Methods in Finance and Energy
New Financial Products and Energy Market Strategies
Bertocchi, M.; Consigli, G.; Dempster, M.A.H. (Eds.)
2011, XXIV, 476 p., Hardcover
ISBN: 978-1-4419-9585-8