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# Optimal Financial Decision Making under Uncertainty

Springer

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*I would like to dedicate the book to my wife Barbara.*

(Daniel Kuhn)

*I would like to dedicate my work to my son Gabriele.*

(Giorgio Consigli)

# Preface

This volume includes chapters by several distinguished colleagues addressing different financial management and valuation problems arising in modern financial markets. When this volume was first conceived, it was motivated by an increasing heterogeneity of mathematical and methodological approaches applied to often rather similar financial optimization problems. In proposing this project to Springer, we aimed at facilitating, when appropriate, a theoretical and computational integration of those methods. To provide a relatively focused book content, the areas of strategic asset allocation, asset-liability management, and asset pricing were considered as reference topic areas. At the time we are writing this Preface, a companion special issue (SI) of *OR Spectrum* has been published (July 2015: Financial optimization: Optimization paradigms and financial planning under uncertainty, *OR SPECTRUM*, 37 (3), Springer) whose table of contents is the following:

J. Dupacova and V. Kozmik: *Structure of risk-averse multistage stochastic programs*

A.K. Konicz, D. Pisinger, K. Rasmussen, and M. Steffensen: *A combined stochastic programming and optimal control approach to personal finance and pensions*

S. Pagliarani and T. Vargiolu: *Portfolio optimization in a defaultable Lévy-driven market model*

M.H.A. Davis and S. Lleo: *Jump-diffusion asset–liability management via risk-sensitive control*

S. Desmettre, R. Korn, P. Ruckdeschel, and F.T. Seifrid: *Robust worst-case optimal investment*

M. Kopa and T. Post: *A general test for SSD portfolio efficiency*

R. Bruni, F. Cesarone, A. Scozzari, and F. Tardella: *A linear risk–return model for enhanced indexation in portfolio optimization*

A. Thiele and E. Cetinkaya: *Data-driven portfolio management with quantile constraints*

T. Driouchi, L. Trigeorgis, and Y.L. Gao: *Choquet-based European option pricing with stochastic (and fixed) strikes*

R. Cerqueti , P. Falbo, G. Guastaroba, and C. Pellizzari: *Approximating multivariate Markov chains for bootstrapping through contiguous partitions*

Jointly, this book and the SI [8] offer an extensive overview of different modeling frameworks and mathematical approaches currently adopted over a relatively wide range of financial domains. In the concluding chapter, we provide a comprehensive review of the main evidences emerging from the work carried out and, relying on the extended set of articles and chapters, assess the state of the art and suggest possible future directions of research.

Ex post we can say that the initial purpose of the volume has been achieved and the collected contributions provide a rather unique set of articles specifically in the domains of portfolio theory and asset-liability management. A general interest to long-term management problems has emerged with an explicit effort by several authors to overcome long-established modeling assumptions, whose consistency with real-world dynamics has been increasingly questioned in recent years. All chapters have gone through a rigorous refereeing process.

A rather short but effective set of characterizing elements of the included chapters may help understanding the volume's profile:

- A sort of looking forward yet back-to-basics motivation underlies several contributions: the relationship between financial risk and investment returns is considered in a very constructive and effective way also removing quite many unrealistic assumptions that in the past have led to substantial model risk and nonoptimal decision-making processes. Not only in the area of portfolio optimization, whose modern era starts with the well-known Markowitz contribution (1952), but to a certain extent also within the chapters devoted to financial engineering and life insurance models, an effort to recast the model formulation and the overall mathematical treatment emerges within more accessible and realistic frameworks, avoiding all those assumptions that in the past have certainly facilitated the mathematical development of the discipline but also to a certain extent jeopardized its practical adoption. Good examples of such generalized effort are provided in this volume by Calafiore [3, 4], Aro and Pennanen [1], Dempster et al. [10], Györfi et al. [16], and Gilli and Schumann [15] and in the SI by Dupačová and Kozmík [13], Thiele and Cetinkaya [6], Driouchi et al. [12], and Kopa and Post [19].
- As a consequence, both in this volume and in the special issue of *OR Spectrum*, data-driven approaches appear at the core of the analysis: this is explicit in Calafiore [4], Pachamanova et al. [22], and Gilli and Schuman [15] and from a different perspective in Györfi et al. [16] and within the SI in Thiele and Cetinkaya [6] and Falbo et al. [5]. Either through a nonparametric approach or by introducing alternative stochastic assumptions on market dynamics, a growing evidence of the removal of once well-established market models is confirmed. The second chapter by MacLean and Zhao [20] presents two increasingly popular financial model extensions that add to the contributions by Davis and Lleo [9] and Pagliarini and Vargiolu [23] in the special issue.

- After such an extended and stressful phase of financial instability that for the first time has affected also sovereign borrowers in developed countries, the need to extend decision horizons and address financial management problems primarily formulated as multi-period and dynamic financial planning problems is evident. This is indeed the element we have primarily considered when deciding to put the survey on multi-period risk measures by Chen et al. [7] as first chapter of the volume. Pachamanova et al. [22], Aro and Pennanen [1], Dempster et al. [10], and Mulvey et al. [21] here as well as Dupačová and Kozmík [13], Konicz et al. [18], Pagliarini and Vargiolu [23], and Davis and Lleo [9] and Desmettre et al. [11] in the special issue rely on such model formulation. In some problem types, primarily those devoted to pension funds' ALM—dynamic long-term formulations also imply a rather central role of longevity risk, one of the relevant risk sources driving nowadays market and agents' behaviors.
- As a final emerging and underlying evidence: bonds and equity are no longer sufficient, and risk management is complex. A prolonged period of high volatility and regime switching and historically low interest rates and vanishing safe market sectors have had profound effects on agents' risk preferences and institutional investors, strategies. As mentioned above, longevity risk is affecting pension funds, management options and their liabilities, but increasingly the source of financial risk is linked to prolonged negative economic cycles. The contributions by Pachamanova et al. [22], Mulvey et al. [21], Aro and Pennanen [1], and Giandomenico and Pinar [14] in this volume as well as those of Driouchi et al. [12] and Konicz et al. [18] in the SI are motivated by the evidence of a growing role in investors' portfolios of assets other than equity and bonds: specifically alternative investments, inflation-linked securities, and life insurance products, with relevant implications on financial institutions hedging strategies and the overall market liquidity.

The chapters are included in the volume following a sequence, which aims at conveying a research and thematic path that we wish to clarify.

The chapter by Chen et al. [7] provides a thorough methodological survey of risk measures theory within dynamic investment theory, setting the stage for the following specifications and extensions. The derivation of a unified set of necessary and sufficient conditions to have multi-period, time-consistent, coherent risk measures represents a central, key contribution of the chapter. The concept of time-consistent investment policies is attracting increasing interest within the formulation and solution of complex optimal portfolio management problems: in recent years, however, different formulations have been attached to the concept. This starting chapter and the first article in the SI, by Dupačová and Kozmík [13], clarify the modeling and methodological implications of such consistency, adopting a discrete time formulation as reference model framework. The chapter immediately following, by MacLean and Zhao [20], has a different aim, but addresses directly the issue of how risk has to be modeled at least in liquid equity markets. MacLean and Zhao [20], in a chapter with strong statistical emphasis, summarize the results of a long-dated research effort, clarifying the implications of regime switching models leading to mixtures of probability distributions, whose statistical characterization is addressed in a rigorous way, against discontinuous return models also leading typically to probability mixtures. The effort to read the data and characterize the markets' stochastic dynamics is associated with what we can refer to as a first step to a model-based optimization approach in which model risk is still an issue. The third chapter by Calafiore [4] moves from such evidence to propose an approach to portfolio allocation which is model-free and relies on data analysis and a clever probabilistic characterization of market returns to present a sequence of results on optimal open- and closed-loop policies in dynamic markets. The last part of Calafiore's chapter is devoted to yet data-driven robust portfolio allocation models and the so-called scenario approach to portfolio optimization. The message is that quite a lot can be done and may lead to superior results, without the need to introduce in the investment problem a stochastic return model. The adoption of portfolio policies will return later in the volume as central element of Mulvey et al. [21].

Robust optimization is the approach now for some years adopted by Pachamanova et al. [22] to address portfolio optimization problems, extended here, however, to a dynamic ALM model specifically for a pension fund. Here, we have an interesting chapter combining a characterization of the underlying market uncertainty based either on historical data or a factor model, an enterprise-wide asset-liability management problem by a pension fund, and a computational study comparing robust and stochastic optimization approaches. The numerical evidence is extended, and this chapter responds to the benchmarking philosophy put forward in the original volume proposal to the publisher. Here, we have a company-wide asset-liability management, and the complex risk sources faced by the decision maker, an institutional investor, are captured in one instance through a factor model. Aro and Pennanen [1], in the following chapter, formulate and solve also an ALM problem, in this case focusing directly on the pension fund liability and the need for the pension fund manager to hedge such liability in an optimal way. Here, the hedging strategy is in discrete time while the return process has continuous state space. The optimization problem aims at determining the minimum required initial wealth needed to hedge the pension liabilities in a market in which perfect hedging and portfolio replication is typically not possible. This chapter addresses thus a fundamental pricing issue for life insurance contracts by postulating an incomplete market and focusing on the extended set of risk sources faced by the pension manager. Aro and Pennanen [1] show, as an aside, that with no need of specific heroic assumptions on the underlying probability space, the associated (imperfect) hedging problem can be formulated and solved relying on convex analysis. Longevity risk is at the center of the analysis.

Asset pricing motivates the contribution by Giandomenico and Pinar [14], where the authors rely on a discrete approach, based on a non-recombining tree, to formulate and analyze the valuation problem for an American option carrying multiple exercise dates: it is an extension of the classical pricing problem with only one possible stopping time, in which the authors generalize the seminal paper by King [17] on contingent claim analysis. As in Aro and Pennanen [1], we have also here a pricing problem formulated as minimal cost problem to hedge a given liability: not only the optimization problem is interesting on its own but also such formulation emphasizes the importance of the hedging problem faced by the derivative writer; this is to be regarded as a necessary condition for the market to develop. Aro and Pennanen [1] in this respect clarify that indeed in modern markets, which are sometimes characterized by poor liquidity, perfect hedging tends to be a pure theoretical construction: partial hedging becomes then the reference market condition and market incompleteness the associated stochastic concept, if one wants to link the analysis to typical mathematical finance concepts. Incompleteness refers to the lack of sufficient financial contracts to hedge every risk source embedded in the contract. It is also true that often life insurers are either unwilling to undertake complex hedging strategies (and rely on high management and underwriting fees) or adopt indirect hedging positions based on correlation analysis. From a methodological viewpoint, a distinctive positive element of Giandomenico and Pinar's [14] article (in addition to the proposed methodology which motivates the contribution) is represented by the initial rigorous description of the probability space and the definition of a scenario tree process for the underlying uncertainty. It is the same underlying statistical formulation typically underlying multistage stochastic programs as those considered by Chen et al. [7], Mulvey et al. [21], and Dempster et al. [10], who, respectively, the latter two, in their chapters address first the implications of optimal portfolio policies in illiquid markets and the second a fundamental methodological implication when dealing with scenario trees with limited branching and the market is incomplete. Among all chapters included in this volume, the one by Mulvey et al. [21], even if with rather complex underlying methodological implications, is the contribution where an advanced knowledge of financial economics and now a days financial markets and agents' policies is mostly needed. Interestingly, the authors present evidence coming from university endowments to clarify a widespread evidence, which is the growing role in modern portfolios of illiquid positions and their implications. The key, innovative motivation of the contribution lies in the construction of a replicating market index able to generate a benchmark for hedging problems as well as portfolio selection problems overcoming at the same time the illiquidity issue arising in markets such as private equity, commodity, and, we add, real estate markets. Mulvey et al. [21] provide a convincing motivation and an effective overview of current challenges faced by institutional investors, after constructing an index with given desirable risk-reward properties that link their study to multistage stochastic programming to suggest a possible approach to formulate and solve a strategic asset allocation problem in the presence of this new asset class of illiquid instruments.

When it comes to formulate a dynamic stochastic programming problem, related to the issue of market incompleteness, Dempster et al. [10] address a key methodological issue in financial optimization when, to ease and allow the solution of large-scale problems, an approximation of typically continuous probability measure by means of discretely sampled scenario trees is needed. The approximation will both lead in general to an approximation bias and result into relatively unstable first-stage decisions. The analysis on implementable decisions is limited to first-stage, root-node decisions and the authors here introduce a method to limit and generate consistent and stable first-stage decisions in the presence of small and coarse scenario trees, as often the case, resulting anyway on large-scale and computationally very challenging programs. Interestingly, Dempster et al. [10] tackle the small sample approximation problem from the viewpoint of a robust optimization approach where the sample is reinterpreted as a problem of incomplete data. This contribution adds to previous studies in which rather than considering the decision space, focus on criteria to best approximate the probability space by introducing appropriate metrics and information measures and devising appropriate scenario reduction and generation methods (see Bertocchi et al. [2] in the same collection).

The following two chapters by Györfi et al. [16] and Gilli and Schumann [15] provide good examples of what we have initially referred to as a valuable effort to move forward in finance theory by recalling some fundamental rules and results that cannot be ignored when addressing maybe theoretical issues but strictly related to applied finance. The chapter by Györfi et al. [16] focuses on a well-known portfolio optimization approach, the growth optimal strategy, based on assumption of log-optimal portfolios to present in a very effective and readable way the set of results that can be called upon to motivate over long-term horizons such decision paradigm and under which market conditions such strategy does indeed satisfies also risk constraints, from which the title given by the authors, the growth optimal investment strategy, is secure too. The chapter presents an extended and useful set of probabilistic and statistical results to show that, applying and deriving a set of inequalities from large deviation theory, it is possible to study the rate of convergence of a log-optimal portfolio return to a target return and that the time in which such target can be achieved under the worst possible market circumstances is still bounded. Before our concluding chapter, the chapter by Gilli and Schumann [15] also motivates the need to address portfolio, only asset, investment problems by considering jointly the issue of model accuracy and realism and the one on the problem solvability. The latter in particular is obviously needed to facilitate the practical adoption of a methodology, but it is also meant not to induce to achieve the problem solution a modification of otherwise realistic model assumptions. Remaining in the area of one-period optimization problems, the authors analyze in a very accessible way the key elements of heuristic solution techniques that can be fruitfully adopted to yield optimal portfolios when other solution approaches are not viable, and the need not to modify the original model assumptions is taken into consideration. The chapter provides an excellent wrap-up of the many issues addressed in the volume, from the formulation of a mathematical description of a portfolio selection problem, consistent with agents' behavioral properties, to the treatment of the stochastic model elements and finally its solution. A case study with an interesting application of a heuristic is presented, relying on the so-called threshold accepting approach, and the authors provide extended evidence of the potential of heuristic methods under several portfolio optimization problem specifications. As other chapters in the volume, independently from the specific application [15], rightly we would add, emphasize the need not to terminate a portfolio selection problem with its solution but to back-test and validate its solution with an appropriate statistical and scenario analysis: only such analysis can validate the theoretical framework and lead to a method practical application.

The concluding chapter aims at consolidating the state of the art through a unified model formulation clarifying the key elements of the chapters included here below and in the special issue and the associated theoretical and applied contributions. An overall assessment of the state of the art on the different financial topics is provided.

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# Contents