PROBABILITY MODELS FOR ECONOMIC DECISIONS, 2nd ed.

by Roger B. Myerson and Eduardo Zambrano

PREFACE

This book is a 'hands-on' introduction to the use of probability models for analyzing risks and economic decisions. It adopts a 'learn-by-doing' philosophy to teach the reader how to use spreadsheets to represent and simulate the uncertainty that the reader may have about a particular situation, and how to analyze the effect of such uncertainty on an economic decision the reader may have to make. Some prior study of probability may be desirable but is not assumed here, as the basic ideas of probability are introduced in the book itself. Throughout this book, the focus is on showing the reader how to use probability in complex realistic situations. All the analytical work in this book is done in Microsoft Excel spreadsheets, because the spreadsheet medium enables students to handle much more complex problems than they could handle with traditional ways of representing mathematical formulas. As a result of this emphasis on spreadsheet modeling, many readers may also learn sophisticated spreadsheet skills from this book. But the main goal of the book is to make the practical power of probability analysis accessible to students at the undergraduate or Master's level in Business Administration, Economics, Public Policy, Public Administration or Business Analytics.

With the advent of the data revolution, individuals in organizations are becoming progressively more sophisticated in the use of quantitative and statistical models. Earlier implementations of those models were *descriptive*, merely using statistics to describe what happened, whereas later implementations were more *diagnostic* and focused on understanding the causal mechanisms underlying what happened. But organizations usually need more than this understanding: They also need to be able to build models that are *predictive* and forecast the possible future consequences of different courses of action, and they ultimately need their models to be *prescriptive*, that is, to help them select among possible courses of actions, based on the objectives of the organization.

Thus, the end goal of any quantitative-analysis course should be to teach students the art of making quantitative models that can give practical insights into real decision problems. But students usually have difficulty with complex models that involve more than two variables, and so quantitative methods are often taught only in the context of simple applications that lack any realistic complexity. The typical result is that even good students who show a mastery of mathematical concepts on their final exams, and even professional economists, often cannot see how to apply these concepts in the real world.

This problem was particularly frustrating to Roger during the 1980s, as he did theoretical research in information economics while he taught probability to MBA students at the Northwestern University's Kellogg School of Management. New advances in information economics were teaching economic theorists that analysis of uncertainty has vital importance for understanding the competitive behavior of economic agents, and probability theory is the foundation for all analysis of uncertainty. But it seemed difficult or impossible to communicate this practical importance of probability analysis to MBA students, even though their career goal was to become the competitively successful economic agents that theorists were studying. So in the late 1980s, Roger began searching for radically new ways to teach probability analysis so that students, after a ten-week MBA-level course, should be able to apply probability analysis to really interesting economic problems and cases. An important motivation in this search was the perception that the powerful new spreadsheet programs had great unexplored potential to transform the way that quantitative analysis is taught. The first edition of this book was the fulfillment of this long process of experimentation and pedagogical development.

Eduardo joined Roger in preparing the second edition of the book in December of 2016, but his involvement with the book goes much farther back in time: Eduardo started teaching this material in 2003 from pdf files downloaded from Roger's website at Northwestern, before the book was first published in 2004. First, he taught it to professional economists at the Venezuelan Congressional Budget Office (2003) and the Venezuelan Central Bank (2004), and then every year since 2007 to upper division undergraduate and Master's students at California Polytechnic State University.

It has now become commonplace for probability and statistics books to do calculations in Excel spreadsheets. In most cases, however, these books have simply taken the old material that professors used to teach on blackboards and have moved it into a spreadsheet. Only rarely have authors asked harder questions about how the new spreadsheet medium should change the content of an introductory quantitative-analysis course. But if we really want to maximize the practical value of the skills that a student can take away from the course, then such questions need to be asked. Analytical methods that seemed too difficult or complex for an audience of applied business and economics students, when we worked on paper and blackboards, now may be straightforward for the same students to master in spreadsheets. On the other hand, there is less need for students to memorize basic computational formulas, now that computer programs with built-in functions and help screens are so universally available.

The most important advantage of teaching spreadsheets is that they make multi-variable models much easier for students to visually understand. Most students lose the big picture when they are asked to think about more than two variables that are represented by letters like "x" and "alpha" on a blackboard, but the same students can visually understand a spreadsheet model with many variables that are represented as cells on a spreadsheet page. Working in spreadsheets brings down the barrier that prevents most students from becoming sophisticated quantitative modelers. Throughout this book, we have tried to show how the methods of probability analysis can be applied to examples of a realistic complexity.

The emphasis on "Monte Carlo" randomized simulation of probability models grew gradually in the development of this book. At first, Roger emphasized other methods of computing probabilities and expected values, but he soon realized that other computational methods generally require special assumptions that limit the scope of applications that we can consider. Monte Carlo simulation is the most versatile general framework for modeling any kind of situation that involves uncertainty, and it has the advantage of letting us really see the uncertainty in our models, as our unknown quantities change at every recalculation. It is our experience that even very well trained theoretical and quantitative economists can improve their ability to illustrate and motivate any advanced concept in probability and decision analysis from approaching it via the Monte Carlo approach. The Monte Carlo framework allowed us to discover new and effective illustrations of conventional statistical topics such as confidence intervals (see Section 2.6) and regression (see Sections 6.7 and 6.8). We have learned a lot from writing and teaching this material, and we have seen our colleagues at different institutions throughout the years learn a lot from engaging with this material as well. Furthermore, it is a lot of fun to teach probability and decision analysis in this way. It allows the teacher to offer a course that is ‘very theoretical’ and ‘very applied’ at the same time, which is very satisfying to students and teachers alike.

As Roger first developed this course, he simultaneously worked to develop his own add-in program (Simtools.xlam) to extend Excel's capabilities for probability analysis. He did not use one of the commercially produced add-ins for statistical risk analysis (like Crystal Ball or @Risk) because he wanted to go farther in decision-analysis and economic modeling with less alteration of Excel's structure. But he found that there was a synergy between the development of the course and the development of the software. Students would regularly ask him to add a function to simplify a difficult part of the course; and as the new software simplified some topics, it became possible to teach other important topics that had previously seemed too advanced. As a result of this process, there are a number of new functions for facilitating decision analysis which were currently unique to Simtools (see GENLINV, CORAND, and CE, for example) and that are now being imitated in other simulation add-ins (such as Risk Solver). Unlike other commercially available add-ins, however, Simtools is open source software, and is freely available at Roger's website:

http://home.uchicago.edu/~rmyerson/addins.htm

We have mostly used this book with MBA, MS in Economics and undergraduate students at Northwestern University and the University of Chicago, and at California Polytechnic State University. Most of our students had some prior exposure to probability theory, but they often had difficulty either recalling it or interpreting it correctly when it was applied in our course. So this book includes an introductory discussion of all the basic probability concepts that are needed to build effective and sophisticated probability models for economic decisions.

How our book is organized

Chapter 1 introduces the basic ideas of probability, how to simulate random variables and how to compute conditional probabilities via Monte Carlo simulation. Chapter 2 introduces discrete random variables, expected values, standard deviations, the Law of Large Numbers and the Central Limit Theorem and explains how these last two concepts help us trust the results of simulation analysis when they contain a sufficiently large number of trials. Next, the concepts of risk aversion and certainty equivalent are introduced in Chapter 3, and continuous random variables are considered in Chapter 4. So in the first four chapters, a large collection of probability distributions are used to simulate a wide variety of problems involving worker efficiency, market entry, oil exploration, repeated investment, and subjective probability assessment. The book then goes over how to simulate correlated random variables and illustrates these concepts in Chapter 5 using problems involving portfolio optimization and probabilistic electoral forecasting. Chapter 6 expands on other forms of building dependence between random variables and connects the material about conditional probabilities developed in Chapter 1 with the linear regression model that is routinely taught in Statistics and Econometric courses.

The later chapters of the book are organized around types of models.

Chapter 7 is, in a sense, "the heart" of the book, as it introduces concepts regarding the strategic value of information, decision trees, game theory and adverse selection, and it applies these concepts to problems regarding operations management, revenue management, and optimal bidding in auctions. Chapter 8 introduces the study of optimal risk sharing, moral hazard, incentive constraints, no-arbitrage, and applies these concepts to a variety of problems involving managerial compensation, asset pricing, and credit rationing. Chapter 9 expands on the study of concepts already introduced in Chapter 4: the evolution of assets whose size grows or shrinks randomly over time. Then the emphasis shifts towards the identification of strategies that would lead to the largest growth rates of those assets, or the largest risk-adjusted growth rate of the assets, and applications to the world of investing, and gambling, are discussed. Concepts of the theory of Real Options are also introduced in this chapter. Chapter 10 is about random arrival processes and we develop the basic concepts about these processes through applications to queuing, inventory management, project length, and the propagation of information or disease.

Chapter 11 takes stock at what has been learned throughout and discusses the causes and consequences of building the wrong model of the decision problem under study. In particular, Chapter 11 discusses sources of 'model risk' and goes over several examples of how model mis-specification can arise in practice, and how it can be mitigated.

Changes in the second edition

We have added extra sections to every chapter, and added two new extra chapters, broadening the applicability of the core techniques in the first edition of the book.

- We add a new section (section 1.9) that describes the workflow behind the construction, implementation and validation of simulation models and that discusses best practices regarding documentation, accountability, and communication of the results of simulation models.

- We introduce the risk measure known as the conditional tail expectation in section 2.8.
- In section 3.1 we present a new interpretation of the risk tolerance parameter of an individual with constant risk tolerance. In section 3.6 we discuss limitations of the expected utility model. In particular, we present and discuss Allais' Paradox and Ellsberg's Paradox.
- In section 4.4 we now study the time diversification fallacy.
- In section 5.8 we introduce a model of probabilistic electoral forecasting in the style of Nate Silver's models of polls and voting, where properly accounting for correlation in polling error across states is key for obtaining quality forecasts.
- In section 6.8 we introduce confidence intervals and prediction intervals, and explain the difference between them, in the context of the standard linear regression model.
- In section 7.4 we develop an airline 'revenue management' optimal reservations application.
- In section 8.7 we develop a model of borrowing and lending decisions in credit markets with adverse selection.
- In section 9.5 we introduce the study of real options, and in section 9.7 we apply the log-optimal investment criterion developed in section 9.6 to situations involving gambling. In section 9.8 we consider decision makers who have a tolerance for risk that increases with wealth and who nevertheless may be averse to growth rate risk.
- Sections 10.1-10.3 used to be in the old Chapter 9, but there is new material in two new sections (10.4-10.5), on dynamic models of the transmission of disease.
- All of the sections in Chapter 11 are new. We discuss sources of model risk and go over several examples of how model mis-specification can arise in practice.

> We also discuss how to mitigate model risk through proper model validation and testing, and through the application of the 'Precautionary Principle' when pertinent.

We also added numerous end-of-chapter problems which span a number of areas of human endeavor where decision analysis is germane. These include: education policy, sports management, health decisions, electoral forecasting, climate change, hotel capacity management, betting markets, agricultural insurance in developing countries, bank lending, disease transmission, securitization, hedge fund performance evaluation, and day trading.

Alternative course designs

There is more than enough material here for a full semester course, and one can make the decision of what part of the material to cover in any given course to depend on student preparation and interest.

For a ten-week course in Probability Models for Economic Decisions/Information Economics where many students needed a review of basic probability, we cover Sections 1.1-1.5 in Chapter 1, all of Chapter 2, Sections 3.1-3.2 and 3.6 in Chapter 3, Sections 4.1-4.7 in Chapter 4, Sections 5.1-5.7 and 5.9 in Chapter 5, Sections 6.1-6.2 and 6.7 in Chapter 6, Sections 7.1-7.2 and 7.5-7.6 in Chapter 7, and Sections 8.1 and 8.3 in Chapter 8.

A 'second' Master's level course in Economics for Decision Analysis could first provide a quick review of how to simulate independent and correlated random variables, and then go over some of the sections not covered on the 'first' course. That could include Section 5.8 in Chapter 5, Section 6.8 in Chapter 6, Sections 7.3 and 7.6 in Chapter 7, either Section 8.5 or 8.6 (or both) and 8.7 in Chapter 8, and as much of Chapters 9-11 as time allows (but making sure to cover at least Sections 9.6 and 9.8 in Chapter 9 and Sections 11.4 and 11.7 in Chapter 11.

The book can also be used to teach a Decision Analysis/Prescriptive Analytics course at the Master's level for Business Administration or Business Analytics students. Such course could cover Sections 1.2-1.6 in Chapter 1, Sections 2.3 and 2.5-2.8 in Chapter 2, Sections 3.1-3.2 in Chapter 3, Sections 4.2-4.3 and 4.5-4.6 in Chapter 4, Sections 5.1-5.6 and 5.8 in Chapter 5, Sections 6.1-6.2 and 6.7-6.8 in Chapter 6, Sections 7.1-7.2 and 7.4-7.6 in Chapter 7, Sections

9.5-9.8 in Chapter 9, Sections 10.1 -10.3 in Chapter 10 and as much of Chapter 11 as time allows.

We have also tried to make this book accessible for self-study or professional enrichment outside of the classroom. When you open up the spreadsheet file for each chapter, you have everything that we would show you in our classrooms.

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