CHANCE ENCOUNTERS

A First Course in Data Analysis and Inference

Christopher J. Wild & George A. F. Seber

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A First Course in Data Analysis and Inference

Christopher J. Wild
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University of Auckland

华南理工大学
图书馆藏书

E2010000607

John Wiley & Sons, Inc.
New York Chichester Weinheim Brisbane Singapore Toronto

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Illustrations courtesy of Dr. Christopher J. Wild
"Dramatic Figures" created by JAK Graphics

This book was set in 10/12 Garamond by Publication Services and printed and bound by Quebecor Printing, Kingsport. The cover was printed by Phoenix Color Corporation.

This book is printed on acid-free paper. ♾

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Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Preface

It is with some trepidation that we launch yet another elementary statistics book into a crowded market! What is distinctive about our book? It is an intuitive, data-oriented, graphical, and computer-oriented introduction to making sense of the world through statistics. We shall expand on each of these features in this preface.

Our Book Is Data Oriented

The main focus is on methods of summarizing and analyzing simple data structures. Our aim is to try to understand the processes producing the data so that we can come to conclusions and make decisions in the face of uncertainty. We emphasize the use of graphs, as they play a major part in the analysis and understanding of data structures. One of our maxims is "Don't do any formal statistical analysis without first graphing your data."

Our approach to data uses modern exploratory ideas. As the chapters unfold, we encourage the reader to see "exploratory" and "confirmatory" as part of the whole. For example, once we have explored the data using a variety of graphics, we choose an appropriate statistical tool to confirm what we see there.

Our examples and exercises use real data sets culled from many disciplines. Applications include the social, physical, biological, and medical sciences; and marketing, finance, and economics. They demonstrate that the subject of Statistics, with a capital S, is relevant to all aspects of our lives. This also allows us to foster the statistical thinking that occurs in the interplay between statistics and the context of a real investigation.

Our Book Is Computer Oriented

Computers have revolutionized the practice of statistics. Once the data have been entered, it is easy to call up a whole range of sophisticated tools and perform what used to be complicated statistical analyses with a few clicks on a keyboard. This has meant

a shift in both teaching and authoring away from the mechanics of the calculations to a greater emphasis on interpreting the results of the computations.

The problem now for writers of general texts, however, is how to make this shift without turning the text into a tutorial manual for some particular software package. To avoid this problem, we have tried to give a broad picture of computational facilities using a selection of packages. In particular, we have opted for the popular Minitab package, originally available as a command language and now menu driven; the Excel spreadsheet; and the function language Splus and its freeware equivalent, R, available from Statlib. In addition to providing indicative computer code throughout, we provide some computer printouts to give readers a feel for what they can expect from a software package, and to show just how easy they are to get! In addition, our many detailed graphical displays highlight the sorts of things you can plot and draw electronically with the current technology.

Our Book Is Intuitive

We have endeavored to write a book that is expositional, chatty, and friendly. We try to explain concepts with words and graphics as much as possible. It is bad enough that students often arrive with an expectation that statistics will be dull without having a dull textbook as well! Students should find this book useful for self-study as well as for college and university courses. Sparsely worded statistics books can, at best, teach mechanical manipulations and mathematical theory. In contrast, we are interested in the big picture and the large statistical ideas. Since such statistical thinking can be demanding for the reader, an emphasis on understanding concepts sometimes demands extensive discussion. Snee [1993] pointed out the great variety in the ways people best learn and think. We have tried to make our presentation work on several levels and to cater to those who think best in verbal or pictorial ways as well as those who are more comfortable with algebra.

An example of this is our intuitive and data-oriented approach to probability in Chapter 4. We use two-way tables to motivate many of the ideas relating to probability and conditional probability. In particular, the instructor will be relieved to find that our approach avoids the need for Bayes' theorem and some of the more complex probability rules. We encourage the reader to be equally at home with percentages, proportions, and probabilities. When we changed wholesale to the two-way table approach, our course administrator found that the panic and overload on help facilities during the probability part of the course largely disappeared, with over half the class being able to successfully answer questions that were formerly answered using Bayes' theorem. We hope this approach will help to arrest the current decline in the teaching of probability that is occurring in elementary statistics courses. Some instructors may not wish to cover all this material, and we mention later how it can be reduced.

Valid Conclusions Serve as a Basis for Action

Statistics is about coming to conclusions in the face of uncertainty. We begin with questions and try to find answers. How the data are obtained—for example, how an experiment is designed—is critical to the quality and validity of the answers, and it also determines which methods of analysis are appropriate. We need to be able to check whether the assumptions underlying the methods are valid. Numerical summaries, plots, and various graphic aids are brought into play to trigger insights and to check the

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underlying assumptions. The interplay between graphics and methods is an important feature of our book, particularly in the later chapters.

Most of the material in this book has been extensively class tested. One of the authors (GAFS) initiated precalculus courses in statistics at Auckland 25 years ago. (The calculus-based courses are much older.) For some time, our first-year program has been successfully run on total quality management lines using a team approach (see Wild [1995] and Wild et al. [1997] for details). This is necessary as we now have nearly 3000 students taking the program each year. We are very grateful to the many people who have contributed and are still contributing to this program. Have we been successful? Two facts speak for themselves. First, our course reaches almost 50% of all new entrants and second, the retention to second-year applied statistics is now approaching 40%. It should be borne in mind that the majority of our students have no intention of proceeding further in statistics! We teach a broad spectrum of students with a wide variety of backgrounds and abilities, so our priority is to try to convey statistical ideas and statistical thinking rather than the mathematics.

Some Special Features

We have included a number of special features to help the reader focus on essentials.

- This book is written as a one-semester text. Time constraints, however, will mean that instructors may wish to select just some of the topics. We suggest ways of doing this in the following section. Instructors may also wish to incorporate some of the additional material that is available on our web site.
- We assume no prior knowledge of statistics. This is a precalculus text with very few mathematical requirements. We assume familiarity with arithmetic skills, simple algebra, some of the most basic concepts from set theory, the summation sign (in a very limited way), averages, square roots, and inequalities. There are occasional "extras," including references, that take the student beyond the general level of the material, which we have starred or relegated to footnotes. These additions should not interfere with the general flow.
- Our exercises come in two varieties: reasonably straightforward "practice" examples that generally concentrate on just one idea and immediately follow the textual development in each section, and more open-ended questions grouped as review exercises at the end of each chapter. In elementary texts there is a tendency for one problem to ask one question, so that knowledge becomes compartmentalized, whereas in real life we get a lot of information thrown at us that we have to sift through and that sometimes requires us to ask our own questions. We often use the context of the investigation underlying a real data set to stimulate statistical thinking.
- Most chapter sections end with a short quiz. Readers can use these to see if they have grasped and retained the key points. Instructors can also use them to generate class discussion.
- Case studies are given in some chapters. These studies expose the reader to some deeper statistical issues.
- Guides to the important learning themes include boxes and detailed summaries at the ends of the chapters.

Using the Material in a One-Semester Course

Although the layout of our book and the table of contents may be deceptively traditional in appearance (but beware of what is between the covers!), our approach uses modern exploratory ideas. Since the expositional and graphic approach to data analysis and inference moves more slowly than a purely methods approach, we don't expect most instructors to get through all the material. Some selection of topics, and even chapters, will be needed. To assist the reader, we have starred some sections that are not required for later use. Rather than simply giving a list of the topics in the chapters, we now wish to go through the chapters, indicating how an instructor might reduce the size of the course.

Chapter 1 is a broad-brush chapter that concentrates on themes and ideas. Many of these themes are picked up and embroidered later in the book. For example, random sampling is an important concept, and it is linked up with surveys and opinion polls. We need to distinguish carefully between experiments and observational studies, especially where the question of causality is concerned. This chapter may also be regarded as a public relations exercise! We explain why statistics is such an important subject and why it pervades our society. Because of the general nature of this chapter, a few key ideas can be summarized and much of the chapter can be assigned to students for reading in their own time. It is, however, an important chapter, as it underpins much of what we are trying to do in this book.

We regard Chapter 2 as a key "nuts and bolts" chapter describing numerical and graphical methods of summarizing data sets. Two features of this chapter are its emphasis on the best ways of displaying tables of data, and both the appeal and drawbacks of some popular types of plots. The chapter is comprehensive, with plenty of figures, and takes the reader slowly through each method. It is computer oriented, and with a computer students can learn these methods quite quickly with the chapter functioning as a manual. Some of the later topics (e.g., the Pareto diagram and segmented bar charts) can be omitted. Chapter 3 is also data oriented, except that our focus here is on a pair of random variables and the graphical methods that best convey their relationship. Regression is introduced informally here, and some instructors may consider the coverage of this topic in Chapter 3 sufficient. The more technical Chapter 12, on regression, can then be omitted. In both Chapters 2 and 3 we focus on the exploratory part of data analysis, whereas in Chapter 12 we emphasize the confirmatory aspects.

Chapter 4 is about probability, and it is here that many students lose their cool! We have already mentioned briefly what we regard as our "user-friendly" approach via two-way tables. Much of the chapter, however, is not needed for later chapters, so that, with the tough time constraints that most instructors work under, substantial trimming is possible, including the topic of conditional probability (Section 4.6) and much of statistical independence (Section 4.7).

The concept of random variable is an important one, and we find it helpful to treat discrete variables (Chapter 5) and continuous variables (Chapter 6) separately. In Chapter 5 the Binomial distribution has a prominent place, and the emphasis is on the model and underlying assumptions rather than on the mathematics. However, the supportive material on general probability functions in Section 5.2 can be reduced or omitted. The notion of expected value is important, but the motivation using data in Section 5.4 could be omitted or relegated to a computer simulation exercise. The idea of a probability density function is introduced intuitively using data in Chapter 5, and the Normal distribution plays a prominent role. Sums and differences of random variables are then discussed in Section 6.4 in anticipation of Chapter 7. Much of the approach in Section 6.4 can be incorporated into a computer exercise. Chapter 7, on

ideas of estimation, is a pivotal chapter as it links the probability chapters (4 to 6) with the remaining inferential chapters (8 to 12). In Chapter 7 we discuss the important ideas of a sampling distribution and approximate Normality. As a first step toward confidence intervals and significance tests, we introduce the idea of a two-standard-error interval in Section 7.5, preparing the way for Chapters 8 and 9. However, much of Section 7.5 could be omitted, and the introduction to the t-distribution in Section 7.6 could be postponed for briefer mention later.

Chapter 8 deals directly with confidence intervals as an idea and uses confidence intervals for means, proportions, and differences between them as examples. Two features that can be omitted (much of Section 8.5) include a discussion of three different sampling situations that arise in media reports where one wishes to compare proportions, and the use and abuse of the margins of error published with opinion polls. Chapter 9 is about hypothesis testing, with much discussion on various practical issues such as the p-value, fixed-significance-level testing, tests versus confidence intervals, and practical versus statistical significance. This is an important chapter, as students tend to have trouble with this topic. Sections 9.4 and 9.6 can be omitted. In Chapters 8 and 9 we have achieved considerable simplification and unification via the repeated explicit use of T = [(estimate − parameter)/standard error] in working with tests and confidence intervals in the many situations where this idea can be applied. A simplifying trade-off has been to use the same form of standard error for both tests and intervals when these are first encountered. Standard usage is inconsistent here (e.g., in the differences between the treatments of means and proportions), and the differences encountered here are too minor to justify the additional layer of obscuring complexity.

In Chapter 10 we take another look at continuous variables. This time we bring all the tools out of our toolkit, including plots, confidence intervals, and hypothesis tests, and we show how these tools interact. We also discuss the important practical issues of assumptions and robustness. In addition to comparing two means, we introduce the analysis-of-variance technique for comparing more than two means. Design issues are looked at more closely, and paired comparisons and randomized designs are discussed. Nonparametric methods are also described, and the sign test is explained in some detail. Welch's approximate procedure, which is now the "default" in many computer packages for comparing two means, is preferred to the usual pooled two-sample test based on the assumption of equal standard deviations. Welch's test is more robust and works well. We regard this chapter as an important one in which data methods are brought together. Instructors, however, who cannot afford this level of detail may omit much of it. In Chapter 11 we try to do the same sorts of things for discrete data as we did for continuous data in Chapter 10. Goodness-of-fit tests and two-way tables are our main focus, and Simpson's paradox is discussed. Chapter 11 is a rather specialized chapter and can be omitted.

As already noted, Chapter 12, which supplements the first part of Chapter 3, discusses the importance of regression as a tool. Formal inference is presented only for the simple linear model along with some residual plots for diagnostic purposes. Correlation is also discussed. If only some of this chapter is to be used, Sections 12.1.3, 12.4.3, 12.4.4, and 12.5 could be omitted. Two optional chapters are available from our web site: Chapter 13 is about control charts; it covers the main types of control charts, and why and how they are used in practice. Chapter 14 is an introduction to time series using simple ideas of smoothing and deseasonalizing data. The discussion on index numbers includes how price indexes are constructed using survey data, something not generally found in other textbooks.

There are two final features. Although we use the computer to work for us, we have included in an appendix some tables that may be useful to the reader. Also, we have provided at the back of the book abbreviated answers to all the chapter exercises and the odd-numbered review exercises. No graphs are included there. Detailed solutions to all exercises, along with the accompanying graphics, are given in the solutions manual.

We have omitted some topics that are often found in elementary statistics books. In particular, combinatorial problems do not appear. However, instructors can easily add this topic to their courses. The term *variance* is seldom used in the main text. We have tried to follow Cobb's [1987] advice of not introducing two concepts when only one (standard deviation as a measure of spread) is really necessary. Normal-theory inferences about variances are not covered, although their extreme sensitivity to non-Normality is stressed and some robust alternatives are mentioned. The software package R previously mentioned was initially developed by fellow Aucklanders Ross Ihaka and Robert Gentleman, and is now burgeoning with a strong international team of collaborators. This package is similar in format to Splus; runs on Windows, Macintosh, and Unix platforms; and is available from Statlib free of charge. Note that Statlib can be reached (under "Links and Resources") from the American Statistical Association homepage at http://www.amstat.org.

Supplementary Materials for Instructors

- A complementary solutions manual is available to adopters of the book from the publisher.
- The Wiley web site, www.wiley.com/college/wild, provides the following resources:
  - Data disk
  - Additional data and exercises
  - PowerPoint slides
  - Two additional chapters
  - Additional topics
  - Teachers' forum

These are available for free download to adopters of the text. The two further detailed chapters on control charts and time series, alluded to earlier, may be particularly suitable for business-type courses. Initial material for additional topics was previously written for earlier drafts of the book when our local courses were larger than they are now. We do not intend to give a detailed list of this material here, but we do refer to some of what is available throughout the book. To give some idea of the sorts of topics, we list just a few: random numbers and their uses; the Poisson, Hypergeometric, Geometric, and Exponential distributions; Normal approximations; and a much more detailed treatment of the Wilcoxon nonparametric test for comparing two samples. We envisage the scope of web site growing to include a broader range of teaching materials and pedagogical ideas.

We welcome any comments or suggestions for improving this book and its supplementary materials. Please feel free to write to or contact us by fax (+64-9-3737108) or e-mail (ws@stat.auckland.ac.nz).

Acknowledgments

Our thanks go to the legion of statistical friends and colleagues who have influenced our thinking, and particularly to the many instructors at Auckland University who have used the drafts of this manuscript over the years and provided helpful feedback. Many of the ideas in this book, and some of the exercises, come from them. We would also like to sincerely thank the following people who reviewed a previous version of the manuscript and provided some very helpful comments:

Aidan Sudbury	*Monash University*
Gary Beus	*Brigham Young University*
Geoffrey McLachlan	*University of Queensland*
Howard Christensen	*Brigham Young University*
James Helmreich	*Marist College*
James Schott	*University of Central Florida*
John Spurrier	*University of South Carolina*
Linda Tappin	*Montclair State University*
Lisa Sullivan	*Boston University*
Maria Ripol	*University of Florida*
Mark Ecker	*University of Northern Iowa*
Mark Irwin	*Ohio State University*
Michael Petersons	*Macquarie University*
Vasant Waikar	*Miami University*
Ian Wright	*Curtin University*

We also owe a considerable debt to the editor, Brad Wiley II, for his important contribution to this book. His insight and penetrating comments combined with the reviewers' suggestions stirred us to undertake a major rewrite of the manuscript.

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C. J. WILD

G. A. F. SEBER

Auckland, New Zealand
May 1999

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