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Informed Bayesian survival analysis

František Bartoš^{1,2*}, Frederik Aust¹ and Julia M. Haaf¹

Abstract

Background: We provide an overview of Bayesian estimation, hypothesis testing, and model-averaging and illustrate how they benefit parametric survival analysis. We contrast the Bayesian framework to the currently dominant frequentist approach and highlight advantages, such as seamless incorporation of historical data, continuous monitoring of evidence, and incorporating uncertainty about the true data generating process.

Methods: We illustrate the application of the outlined Bayesian approaches on an example data set, retrospective re-analyzing a colon cancer trial. We assess the performance of Bayesian parametric survival analysis and maximum likelihood survival models with AIC/BIC model selection in fixed-n and sequential designs with a simulation study.

Results: In the retrospective re-analysis of the example data set, the Bayesian framework provided evidence for the absence of a positive treatment effect of adding Cetuximab to FOLFOX6 regimen on disease-free survival in patients with resected stage III colon cancer. Furthermore, the Bayesian sequential analysis would have terminated the trial 10.3 months earlier than the standard frequentist analysis. In a simulation study with sequential designs, the Bayesian framework on average reached a decision in almost half the time required by the frequentist counterparts, while maintaining the same power, and an appropriate false-positive rate. Under model misspecification, the Bayesian framework resulted in higher false-negative rate compared to the frequentist counterparts, which resulted in a higher proportion of undecided trials. In fixed-n designs, the Bayesian framework showed slightly higher power, slightly elevated error rates, and lower bias and RMSE when estimating treatment effects in small samples. We found no noticeable differences for survival predictions. We have made the analytic approach readily available to other researchers in the RoBSA R package.

Conclusions: The outlined Bayesian framework provides several benefits when applied to parametric survival analyses. It uses data more efficiently, is capable of considerably shortening the length of clinical trials, and provides a richer set of inferences.

Keywords: Bayesian, Survival analysis, Model-averaging, Bayes factor, Historical data

Background

There has been a steady increase in the popularity and interest in Bayesian statistics in the past years [1]. In this paper, we leverage the advantages of the longstanding Bayesian estimation [2], hypothesis testing [3], and model-averaging [4] approaches and apply them to

parametric survival analysis. This type of Bayesian survival analysis is possible thanks to the recent development of flexible tools for fitting Bayesian models (such as JAGS [5] and Stan [6]) and efficient techniques for estimating marginal likelihoods (such as bridge-sampling [7–9]).

Survival analysis is a frequently used method with important applications in evaluating lifetime outcomes in clinical trials [10, 11]. The most commonly used version of survival analysis is the non-parametric Cox proportional hazard model, which does not require specification of the baseline hazard [12]. There are,

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Bayesian Survival Analysis Bayesian Survival Analysis:

Bayesian Survival Analysis Joseph G. Ibrahim, Ming-Hui Chen, Debajyoti Sinha, 2013-03-09 Survival analysis arises in many fields of study including medicine biology engineering public health epidemiology and economics This book provides a comprehensive treatment of Bayesian survival analysis Several topics are addressed including parametric models semiparametric models based on prior processes proportional and non proportional hazards models frailty models cure rate models model selection and comparison joint models for longitudinal and survival data models with time varying covariates missing covariate data design and monitoring of clinical trials accelerated failure time models models for multivariate survival data and special types of hierarchical survival models Also various censoring schemes are examined including right and interval censored data Several additional topics are discussed including noninformative and informative prior specifications computing posterior quantities of interest Bayesian hypothesis testing variable selection model selection with nonnested models model checking techniques using Bayesian diagnostic methods and Markov chain Monte Carlo MCMC algorithms for sampling from the posterior and predictive distributions The book presents a balance between theory and applications and for each class of models discussed detailed examples and analyses from case studies are presented whenever possible The applications are all essentially from the health sciences including cancer AIDS and the environment The book is intended as a graduate textbook or a reference book for a one semester course at the advanced masters or Ph D level This book would be most suitable for second or third year graduate students in statistics or biostatistics It would also serve as a useful reference book for applied or theoretical researchers as well as practitioners [Bayesian Survival Analysis](#) Joseph G. Ibrahim, Ming-Hui Chen, Debajyoti Sinha, 2014-01-15 **Bayesian survival analysis** Joseph George Ibrahim, Ming-Hui Chen, Debajyoti Sinha, 2001 [Bayesian Survival Analysis](#) Keith Rowland Abrams, 1992 **Bayesian Survival Analysis of Risk Factors Associated with Longevity in the Framingham Heart Study** Darleen Marie Shank, 1997 *Shrinkage Estimation in Nonparametric Bayesian Survival Analysis* Kamta Rai, Vyaghreswarudu Susarla, John Van Ryzin, Rand Corporation, 1979 [Bayesian Survival Analysis for Prognostic Index Development with Many Covariates and Missing Data](#) Xiaohui Zhao, University of Newcastle upon Tyne. School of Mathematics and Statistics, 2010 [Modelling Survival Data in Medical Research](#) David Collett, 2023-05-31 *Modelling Survival Data in Medical Research* Fourth Edition describes the analysis of survival data illustrated using a wide range of examples from biomedical research Written in a non technical style it concentrates on how the techniques are used in practice Starting with standard methods for summarising survival data Cox regression and parametric modelling the book covers many more advanced techniques including interval censoring frailty modelling competing risks analysis of multiple events and dependent censoring This new edition contains chapters on Bayesian survival analysis and use of the R software Earlier chapters have been extensively revised and expanded to add new material on several topics These include methods for assessing the predictive ability of a model joint

models for longitudinal and survival data and modern methods for the analysis of interval censored survival data Features Presents an accessible account of a wide range of statistical methods for analysing survival data Contains practical guidance on modelling survival data from the author s many years of experience in teaching and consultancy Shows how Bayesian methods can be used to analyse survival data Includes details on how R can be used to carry out all the methods described with guidance on the interpretation of the resulting output Contains many real data examples and additional data sets that can be used for coursework All data sets used are available in electronic format from the publisher s website Modelling Survival Data in Medical Research Fourth Edition is an invaluable resource for statisticians in the pharmaceutical industry and biomedical research centres research scientists and clinicians who are analysing their own data and students following undergraduate or postgraduate courses in survival analysis

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computation for practitioners Because these theoretical and technological developments introduce new questions and challenges and increase the complexity of the Bayesian framework this book brings together experts engaged in groundbreaking research on Bayesian inference and computation to discuss important issues with emphasis on applications to reliability and survival analysis Topics covered are timely and have the potential to influence the interacting worlds of biostatistics engineering medical sciences statistics and more The included chapters present current methods theories and applications in the diverse area of biostatistical analysis The volume as a whole serves as reference in driving quality global health research

Survival Analysis: State of the Art John P. Klein, P.K. Goel, 2013-03-09 Survival analysis is a highly active area of research with applications spanning the physical engineering biological and social sciences In addition to statisticians and biostatisticians researchers in this area include epidemiologists reliability engineers demographers and economists The economists survival analysis by the name of duration analysis and the analysis of transition data We attempted to bring together leading researchers with a common interest in developing methodology in survival analysis at the NATO Advanced Research Workshop The research works collected in this volume are based on the presentations at the Workshop Analysis of survival experiments is complicated by issues of censoring where only partial observation of an individual's life length is available and left truncation where individuals enter the study group if their life lengths exceed a given threshold time Application of the theory of counting processes to survival analysis as developed by the Scandinavian School has allowed for substantial advances in the procedures for analyzing such experiments The increased use of computer intensive solutions to inference problems in survival analysis in both the classical and Bayesian settings is also evident throughout the volume Several areas of research have received special attention in the volume

Bayesian Nonparametric Data Analysis Peter Müller, Fernando Andres Quintana, Alejandro Jara, Tim Hanson, 2015-06-17 This book reviews nonparametric Bayesian methods and models that have proven useful in the context of data analysis Rather than providing an encyclopedic review of probability models the book's structure follows a data analysis perspective As such the chapters are organized by traditional data analysis problems In selecting specific nonparametric models simpler and more traditional models are favored over specialized ones The discussed methods are illustrated with a wealth of examples including applications ranging from stylized examples to case studies from recent literature The book also includes an extensive discussion of computational methods and details on their implementation R code for many examples is included in online software pages

Case Studies in Bayesian Statistical Modelling and Analysis Clair L. Alston, Kerrie L. Mengersen, Anthony N. Pettitt, 2012-10-10 Provides an accessible foundation to Bayesian analysis using real world models This book aims to present an introduction to Bayesian modelling and computation by considering real case studies drawn from diverse fields spanning ecology health genetics and finance Each chapter comprises a description of the problem the corresponding model the computational method results and inferences as well as the issues that arise in the implementation

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Handbook of Survival Analysis John P. Klein, Hans C. van Houwelingen, Joseph G. Ibrahim, Thomas H. Scheike, 2016-04-19 Handbook of Survival Analysis presents modern techniques and research problems in lifetime data analysis This area of statistics deals with time to event data that is complicated by censoring and the dynamic nature of events occurring in time With chapters written by leading researchers in the field the handbook focuses on advances in survival analysis techniques covering classical and Bayesian approaches It gives a complete overview of the current status of survival analysis and should inspire further research in the field Accessible to a wide range of readers the book provides An introduction to various areas in survival analysis for graduate students and novices A reference to modern investigations into survival analysis for more established researchers A text or supplement for a second or advanced course in survival analysis A useful guide to statistical methods for analyzing survival data experiments for practicing statisticians

Bayesian Thinking, Modeling and Computation , 2005-11-29 This volume describes how to develop Bayesian thinking modelling and computation both from philosophical methodological and application point of view It further describes parametric and nonparametric Bayesian methods for modelling and how to use modern computational methods to summarize inferences using simulation The book covers wide range of topics including objective and subjective Bayesian inferences with a variety of applications in modelling categorical survival spatial spatiotemporal Epidemiological software reliability small area and micro array data The book concludes with a chapter on how to teach Bayesian thoughts to nonstatisticians Critical thinking on causal effects Objective Bayesian philosophy Nonparametric Bayesian methodology Simulation based computing techniques Bioinformatics and Biostatistics

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