APPLICATIONS OF SIMULATION METHODS IN ENVIRONMENTAL AND RESOURCE ECONOMICS

THE ECONOMICS OF NON-MARKET GOODS AND RESOURCES

VOLUME 6

Series Editor: Dr. Ian J. Bateman

Dr. Ian J. Bateman is Professor of Environmental Economics at the School of Environmental Sciences, University of East Anglia (UEA) and directs the research theme Innovation in Decision Support (Tools and Methods) within the Programme on Environmental Decision Making (PEDM) at the Centre for Social and Economic Research on the Global Environment (CSERGE), UEA. The PEDM is funded by the UK Economic and Social Research Council. Professor Bateman is also a member of the Centre for the Economic and Behavioural Analysis of Risk and Decision (CEBARD) at UEA and Executive Editor of Environmental and Resource Economics, an international journal published in cooperation with the European Association of Environmental and Resource Economists. (EAERE).

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Applications of Simulation Methods in Environmental and Resource Economics

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Springer

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN-10 1-4020-3683-3 (HB)
ISBN-13 978-1-4020-3683-5 (HB)
ISBN-10 1-4020-3684-1 (e-book)
ISBN-13 978-1-4020-3684-2 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springeronline.com

Printed on acid-free paper

Printed in the Netherlands.

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Foreword

The growth of simulation based methods over the past fifteen years, together with the accompany improvements in computational power, has ushered in a new era of applied research in economics generally and environmental and resource economics in particular. The analyst is no longer constrained to choose from among a limited set of models simply because they yield a convenient functional form for, say, the log-likelihood function in a discrete choice model or the posterior distribution in a Bayesian analysis. Instead, one can specify more flexible models that allow agents to reveal patterns in their behavior through the data. Maximum simulated likelihood procedures can be used to allow for complex patterns of correlations among choice alternatives in a mixed logit or multinomial probit model of discrete choice, rather than having to impose a priori the rigid structure of the more traditional multinomial or nested logit models. Bayesians can specify prior distributions that reflect their actual prior beliefs, rather than being limited to a convenient set of conjugate priors. Indeed, it is increasingly the case that the questions that can be addressed in applied research are constrained by limitations in the available data, rather than by the models that can be feasibly estimated.

Despite the promise offered by simulation methods, many practitioners continue to avoid their use, daunted by the perceived difficulty of the techniques themselves or the prospect of programming the routines in software packages such as GAUSS or Matlab. Moreover, graduate students often receive little or no training in simulation methods and are forced to learn the necessary tools on their own. This volume provides a valuable resource in this learning process. Alberini and Scarpa have gathered in one place eighteen papers covering a wide range of simulation issues and techniques with applications to environmental and natural resource problems. The topics range from estimation procedures, such as Train and Weeks (in the opening chapter) use of a Bayesian framework and MCMC methods to obtain estimates for the mixed logit model, to discussions of important computational issues (e.g., the choice of random number generators and the tradeoffs between using Gaussian quadrature versus simulation methods for integration). The authors, all experienced practitioners in the use of simulation methods, provide valuable and practical insights into the procedures. In most cases, step-by-step algorithms are provided for the simulation method under discussion, with the underlying computer code available from the respective authors. For those of us who have made extensive use of the mixed logit code graciously provided by Kenneth Train in the past, it is clear that such computer code can substantially lower the learning costs associated with simulation based methods. Just as important, the authors provide insights into the limitations and potential pitfalls associated with use of simulation based methods. Simulation methods greatly expand the set of models that can be feasibly estimated in a given setting. Unfortunately, this makes it all the more important to understand the underlying limitations of a model and how the ways in which they are structured and estimated, rather than the data itself, can determine the outcomes of an analysis. The complex econometric methods that simulation techniques allow are still no substitute for sound economic modeling and careful data collection. The insights provided in this volume should help practitioners in the proper use of simulation based methods.

Joseph Herriges
Iowa State University
Ames, Iowa, February 2005

Acknowledgments

As any editor of a similar volume will know, and it is quite easy to imagine, this product can rarely be completed without the contribution of many. Credit must be given where credit is due.

The volume collects the work of 36 authors in 18 papers, plus the editors' assistants. We are indebted to all of them, for their work, patience and support. A special 'thank you' must go to Kenneth Train for both the initial inspiration and the encouragement throughout. Had it not been for his work, this volume would never have been conceived.

In the process of scientific review of the manuscripts we took advantage of the generosity of time of many colleagues who are not co-authors of any chapter in the volume. We are thankful to—amongst others—Elisabetta Cherchi (University of Cagliari), Andreas Kontoleon (University of Cambridge), Gary Koop (University of Leister), and Luis Rizzi (Catholic University of Santiago, Chile) for their constructive comments during the reviewing effort.

We are also very grateful to those who pined over the translation from MSword documents into the LaTeX typeset. These include many that helped along the way, but we feel we should name the members of the editorial team at the Environment Department of the University of York, who really worked at the "coal-face": Nesha Beharry, Chung-Ting Chang and Jan Minx for their hard and proficient work. I am sure that for some of them the 'discovery' of LaTeX involved substantial effort.

The help and guidance provided by Springer publisher, and in particular by Esther Verdries, are also gratefully acknowledged.

Introduction

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1. Background and motivation

This volume collects a series of empirical research papers in environmental and resource economics with one common feature: They all make use of simulation methods (SMs). The rapid development of the computational power in computers that we have experienced in the last twenty years has brought about momentous changes in the techniques used in applied economics.

This has unleashed an unprecedented growth in the versatility of behavioural models that can be empirically investigated, provided that adequate data become available. The new fruits of this increased computational power are now being harvested throughout economics, with many applications in environmental and resource economics.

Anthony Fisher, in his 2004 keynote speech to the European Association of Environmental and Resource Economists in Budapest was asked to list what he thought were the three most promising areas of research in the discipline. In his answer he mentioned the promise of benefit transfer, experimental economics and simulation based methods.

The growth in computational power and the widespread adoption of SMs has also posed new questions. With new research frontiers opening up to the profession, new challenges have emerged, and now need to be faced and successfully tackled. At the same time old distinctions between paradigms—such as the classical *vs* the Bayesian dichotomy—have sometimes become blurred and hence lost some of their rationale and methodological bite (as shown in chapter 2), and become even complementary (as shown in chapters 7 and 8).

The considerable dynamism that characterizes this area of research makes it difficult to regularly incorporate such advances into conventional university courses. It is our perception that—perhaps with the exception of large research establishments—most post-graduate training in environmental and resource economics today does not include adequate exposure to SMs. We hope that this volume will help fill this gap, and that PhD supervisors will refer their supervisees to it for a primer on the subject.

This collection was hence conceived to bring together in a single volume a significant selection of research papers by leading practitioners in this field. Each chapter has been peer-reviewed either by contributors or by other qualified reviewers (see acknowledgements). At the same time the structure of writing was deliberately pedagogical in nature.

Many areas and research questions within natural resource and environmental economics naturally lend themselves to the application of simulation methods. The prevalence of articles on non-market valuation in this volume mirrors the large role played by this line of research in the profession at the moment.

As any researcher using SMs will recognize, the writing of specific codes to implement simulation algorithms is a key component of a researcher's toolkit. Most of the contributors to this collection have very kindly agreed to making their respective codes available (of course, without any guarantee). Considering the amount of time that this activity normally requires, their generosity should—in our opinion—generate substantial external benefits. We very much hope that those readers who will use these routines in their own research will take the time to mention the source of these routines in their published works.

The chapters of the volume were arranged on the basis of some themes. In what follows we briefly discuss each theme and its chapters.

2. Heterogeneity in discrete choice models

Simulation methods are increasingly being used to estimate discrete-choice models, and the related welfare measures for non-market goods. Recent research in this area has attempted to incorporate constraints and checks so as to ensure that measures of marginal prices, willingness to pay, and other relevant welfare statistics are behaviourally plausible in the presence of unobserved heterogeneity. For this reason the first four chapters in this volume are concerned with heterogeneity in discrete choice models.

In the first chapter, Kenneth Train and Melvyn Weeks explore the consequences of framing heterogeneity in the *WTP* space, in contrast with the more common option of heterogeneity in preference space. The estimation is conducted in a Bayesian framework using Monte Carlo Markov Chains and the authors highlight correlation issues previously overlooked in the literature. The novelty of introducing parameter heterogeneity *directly* in the expenditure function is no doubt very appealing and it has already proven to be a preferred approach by many non-market valuation analysts since its introduction by Cameron, 1988 and Cameron and James, 1987 in the contingent valuation literature.

In Chapter 2, William Greene, David Hensher and John Rose focus on the use of mixed logit with bounded parameter distributions to achieve behaviourally plausible *WTP* distributions and on the derivation of individual-specific *WTP* estimates conditional on observed choices, which they compare with the conventional population-based statistics. They pay special attention to large and implausible *WTP* values. The technique they propose is implemented in Nlogit, a popular econometric package. We expect that the approach they suggest will be used in numerous applied papers in the future, especially because some preliminary evidence seems to suggest that the distribution of these conditional estimates in the sample is less prone to the presence of behaviorally implausible value estimates.

Heterogeneity of *WTP* distributions is also the focus of chapter 3, authored by David Layton and Klaus Moeltner who present a contingent valuation study of *WTP* to avoid power outages. The authors face numerous econometric challenges and propose an approach that deals with all of these based on a Gamma distribution with heterogeneity addressed by a scale parameter with log-normal distribution. Such creative use of mixed and flexible models is one of the gifts delivered by advances in SMs.[1]

In the final chapter of this section (chapter 4) Stephane Hess, Michel Bierlaire and John Polak put forward a potential solution to the problem of confounding of correlation between alternatives and taste variation across individuals. To separately address these issues without confounding they use a mixed generalized extreme value model. As the use of mixed logit error-component models becomes more established in the environmental economics literature (see for example Herriges and Phaneuf, 2002 and chapter 13 in this volume) this line of research will become increasingly important. The estimation is conducted using BIOGEME, the software developed by Bierlaire and available from this author.

[1]These authors employed MatLab code and have decided to make it available upon request.

In chapter 5, Joe Cooper specifies a multinomial probit model (MNP) for stated-preference adoption or non-adoption of one of five best management practices under the federal Environmental Quality Incentive Program given a hypothetical payment to the farmer. Estimation of the MNP requires maximum simulated likelihood methods. Cooper further incorporates the semi-parametric approach to modeling binary data willingness-to-accept (*WTA*) responses first introduced by Creel and Loomis, 1997, and illustrates this model using the data from a survey of U.S. farmers. A likelihood ratio test confirms Cooper's suspicions that farmer *WTA* for one practice is not independent of that for another practice. An approach for predicting *WTA* for one practice conditional on the bids for the other practice is then proposed.

In chapter 6, Andreas Ziegler is motivated by a broad question about the role of environmental regulation and firm self-regulation: What factors drive firms to adopt environmental product innovations? Specifically, is the adoption of such innovations affected by market conditions, including competitive pressure, client relations, etc.? Ziegler compares the multinomial logit model with the multinomial probit model, where the latter is estimated using the Geweke-Hajivassiliou-Keane simulator. Ziegler finds that the simulated ML estimates of the multinomial probit model are unreliable, a result that he attributes, among other things, to the nature of the multinomial model itself, where the only explanatory variables are firm characteristics that do not vary across alternatives. He concludes that the multinomial probit model offers few new insights above and beyond those of the multinomial logit.

3. Bayesian applications

The following section collects five chapters that employ Bayesian estimation techniques. They either compare these to classical ones, or show how these can supplement classical ones. Of course this is another area in which SMs have had a tremendous impact. In the opening chapter of this section (chapter 7), Ken Train and Garrett Sonnier illustrate the use of efficient Bayesian estimation in deriving taste-parameter distributions with bounds that reflect behavioural expectations and full correlation across parameters of the utility function. The associate GAUSS code has been available for some time from the web-page of Prof. Train, and it is very flexible. Their empirical application reports on a study of preferences for environmentally friendly car engine solutions, comparing electric, hybrid and conventional engines.

Chapter 8, which we judge very useful from a teaching point of view. is contribution by Roger van Haefen and Dan Phaneuf, two leading researchers in the field of demand systems for quality-differentiated goods in the Kuhn-Tucker framework. This line of research has benefited greatly from the use of SMs. In this chapter the various challenges that the profession has had to face to implement this elegant approach to the travel-cost method are carefully described, and the role of SMs highlighted in both parameter estimation and derivation of welfare measures form moose hunting. The authors propose three estimation approaches, one of which uses Bayesian techniques, and make their GAUSS code available to the reader. Hopefully this chapter will lead to a more widespread use of this approach, which is so far the most theoretically consistent with consumer theory.

Holloway, Tomberlin and Irz in chapter 9 move our attention to the use of SMs to estimate production efficiency in a trawl fishery with a purely Bayesian hierarchical approach based on specifically developed error-component model and MCMC-assisted estimation. Estimation of efficiency frontiers is a 'classic' problem in empirical production economics and of high relevance in the economics of fishery resources.[2] Powerful and robust Bayesian techniques of this kind are obvious assets in the tool-kit of applied resource economists.

In chapter 10 Layton and Levine address the issue of how to incorporate previous information of past studies of pilot and pre-test surveys to improve the quality of estimation from the final survey data. This is a natural context of application for a Bayesian analytical framework, especially in multi-stage data collection in which sequenced updating of posteriors is possible. As computer aided survey administration becomes more widespread such techniques will become of greater value. The authors illustrate the value of their approach using stated preference data on surveys for the protection of the northern spotted owl in Seattle, Washington.

Araña and León in chapter 11 illustrate how to analyze discrete-choice contingent valuation data single- and double-bounded in a Bayesian framework. They run Monte Carlo experiments to compare conventional maximum likelihood analysis with Bayesian ones and find the latter improves the performance of the model, particularly with relatively small samples. This result is of great interest given the cost of contingent valuation surveying.[3]

4. Simulation methods in dynamic models

Two chapters in this book are dedicated to the use of SMs for solving and exploring the characteristics of dynamic models. This area of research is of germane importance in natural resource economics.

Richard Woodward, Wade Griffin and Yong-Suhk Wui focus on solutions and on approximation to solutions of dynamic programming (DP) models that are tied to large simulation models. They compare and discuss the pros and cons of a direct approach, in which the simulation model is embedded in the

[2]The authors employ MatLab and the code is available upon request.
[3]Their GAUSS code is available upon request from the authors.

DP algorithm, to an indirect one in which functional relationships are approximated using an econometrically estimated meta-model. In their application they tackle a complex management problem in the red snapper fishery in the Gulf of Mexico. The policy variables examined here are (i) the total allowable catch (TAC) for the red snapper fishery, and (ii) the distribution of the TAC between commercial fishermen and recreational anglers. Woodward *et al.* find that the metamodeling approach to be less computationally burdensome, but the direct approach is superior in terms of plausibility of results, consistency with economic theory, and forecasting performance.

In chapter 15, Bill Provencher and Kenneth Baerenklau make a valuable point in emphasizing that most empirical dynamic models—which address issues such as land development decisions, livestock grazing rates, and timing of timber harvesting—have been based on stylized reduced-form specifications. They therefore present an approach to structural form estimation and apply it to the timber harvesting problem of Brazee and Mendelsohn, 1988. They also discuss the difficulty of distinguishing whether microeconomic data are generated by static or dynamic behaviour even with maintained structural assumptions about the form of the intra-period utility or profit function. We find their contribution to present an important pedagogical perspective.

5. Monte Carlo experiments

Chapters 13 and 12 are dedicated to one of the major work-horses of SMs: context-specific Monte Carlo experiments devised to explore the finite sample properties of estimators for which econometric theory provides the researcher only with asymptotic results.

Riccardo Scarpa, Silvia Ferrini and Ken Willis—in chapter 13—focus on the econometrics of choice experiments in the format commonly used for non-market valuation in environmental economics. In this context it is customary to include in each choice set the "status quo" response option in addition to the other alternatives. Economists and psychologists have, however, worried about status-quo biases and other undesirable response effects induced by the inclusion of this response option, and in this chapter Scarpa *et al.* investigate these effects. They compare three models, two of which are commonly used by practitioners (conditional logit with one status-quo alternative-specific constant and nested logit), while the third is a more flexible mixed logit error component model which nests the other two under specific conditions. Their Monte Carlo results suggest that the mixed logit error component model they proposed is robust to mis-specification errors over a range of commonly employed sample sizes, and should be preferred over the other more commonly employed two.[4]

[4]Their GAUSS code is made available upon request.

In chapter 12, Margarita Genius and Elisabetta Strazzera follow up on an influential paper by Carson, Groves and Machina, 2000, in that they study models appropriate for checking the incentive-compatibility properties of dichotomous choice contingent valuation questions. Briefly, in single-bounded referendum questions the respondent is asked to say whether he would vote in favor or against a public program if the cost to him or her is *X*. The responses to these referendum questions are incentive-compatible, but statistically inefficient. To refine information about *WTP*, researchers usually include dichotomous-choice follow-up questions. However, the follow-up questions are not incentive compatible.

This paper focuses on bivariate models of *WTP*, e.g. models in which the response to the initial and follow-up payment question are assumed to be driven by two different-and unobserved-*WTP* amounts. The two latent *WTP* amounts are allowed to be correlated. Specifically, the authors consider (i) a bivariate model that restricts the coefficients in the first and second equation to be identical, (ii) a bivariate model with a shift (following Carson et al.), and (iii) a model that truncates the bivariate distribution to allow for the incentives to be different for individuals who answer no to the initial payment question, and individuals who answer yes to the initial payment question.

The authors also worry about using bivariate normal distributions when the true distribution is not normal, and introduce a Joe copula, i.e., a joint distribution for two variables with specified marginals. For each of the three possible data generating processes ((i), (ii) and (iii)), the authors fit all proposed models, examine the effect of fitting a bivariate normal model when the distribution of the latent *WTP* amounts is not a bivariate normal, and experiment with Joe copula models. They find that the latter are flexible, perform well, and have a good track record of convergence, especially when the models based on the traditional bivariate approach do not converge easily.

6. Computational aspects

Although computational aspects are dealt with throughout the volume, the pedagogical intention of this volume on SMs in environmental and resource economics required that we examine such issues in some detail. Accordingly, the last three chapters deal with these specific aspects of simulation-based methods.

Perhaps one of the main concerns in simulation studies using Monte Carlo techniques is the quality of pseudo-random generators. Giovanni Baiocchi deals with these and related aspects such as reproducibility of results and reporting in chapter 16. He reports the outcomes of a battery of tests specifically meant to assess the quality of different pseudo-random generators employed in software commonly used by resource and environment economists. Many of these outcomes are surprising. We believe readers will find this chapter very useful for learning about potential pitfalls of simulation-based tools.

Bill Breffle, Ed Morey and Donald Waldman in chapter 17—instead— focus on simulation noise in a comparison between quadrature and simulation techniques with pseudo-random draws in approximating integrals without a closed-form in binary probit models. Their context of application is stated preference data from a sample of Green Bay anglers. They find that in some circumstances quadrature affords computational gains with respect to simulation-based estimation.[5]

Finally, simulation noise is also the main theme of chapter 18 by John McPeak. Using his data-set on land use decisions by Kenyan pastoralists, he focuses on simulation noise due to various sources in the bivariate tobit model. He considers how variable characteristics influence parameter variability across estimation runs, and identifies specific characteristics that influence variability in his results. While McPeak concludes that in his dataset simulation noise is not large enough to lead the analyst to incorrect conclusions, his concern is of high relevance to SMs practitioners, who—in our opinion—should systematically carry out tests to check whether this is indeed the case. As a consequence his approach is of general interest.[6]

7. Terminology

In an ideal world there would be a one-to-one mapping between terms and concepts. Initially we intended to standardize the terminology throughout the book in as much as possible. Although we tried, we now feel we did not go very far with it. As a result, for example, many acronyms of models across chapters may refer to different econometrics specifications. While an apology in this sense is due to the reader, we feel that the diversity of terms in this book reflects that in the current literature. Hopefully, in future there will be a natural evolution of technical jargon towards some kind of standard.

[5] Their GAUSS code is made available upon request.

[6] John McPeak also uses code for GAUSS and he makes it available upon request.