Introduction

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INTRODUCTION

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Econometric inference using simulation techniques has developed greatly in recent decades. Simulation techniques make use of sequences of pseudo-random numbers which are generated by a computer procedure. In an earlier period, during the nineteen-fifties and -sixties, simulation techniques were already used to study the small sample properties of econometric estimators and test functions in small, artificial models of economic processes. The main reasons for the increased research interest in simulation techniques are: (1) technological advances in microcomputers with powerful processors; and (2) advances in statistical methods dealing with simulation. As a consequence, the study of algorithms for efficient numerical integration by means of simulation techniques has become an important research area in econometrics.

There are at least three areas of econometric inference where the use of simulation methods has been successful.

(i) In Bayesian inference, the evaluation of the integrals defined in posterior and predictive moments became a topic of interest through the work of Kloek and Van Dijk, Drèze and Richard, Zellner and Rossi, Geweke, and Gelfand and Smith for example. Simulation methods, in particular Gibbs sampling and importance sampling, allow researchers to study more flexible families of probability distributions in the parameter space than the extreme cases of a natural conjugate or a uniform family. It also allows the incorporation of non-linear restrictions on the parameters and it enables researchers to study functions of interest of parameter values. The trade-off between analytical tractability and richness of families of probability distributions has been moved more in favour of the latter. Recently applications deal with financial models, unemployment analysis, and cointegration models.

(ii) In classical inference, the approximation by simulation techniques of criterion functions in which integrals appear has become an important topic of research. The main criterion functions considered are those corresponding to the Generalized Method of Moments; the Maximum Likelihood Method; and the Pseudo Maximum Likelihood Methods. The problems, which have been studied, are the statistical and numerical accuracy of the various proposed approximations. In dynamic models, different approaches are relevant depending on whether it is easy to simulate within the conditional distribution of the observable endogenous variables given their past values (and the values of an exogenous process).

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(iii) The solution and stochastic simulation of dynamic econometric models, in particular, general equilibrium models, is another area of recent research.

The areas described cover a wide range of research topics and the papers collected in this volume deal with only some of these. In the first three papers a Bayesian analysis of generalizations of the linear model, $y = X\beta + \varepsilon$, are given. Andrews *et al.*, consider the problem of increased fuel efficiency of passenger cars and trucks. This is dependent upon established technology which is described by an extensive list of variables. Using a unique data set on several automobile brands, a hierarchical Bayesian model with fixed and random effects, with constraints on the equation parameters, and with unequal variances is constructed. Combining a weakly informative prior with the likelihood gives a posterior that is analysed by simulation methods. Using Gibbs sampling, one generates random drawings from the posterior and studies different features of the fuel efficiency process. The results indicate high variability in the posterior mean amongst more than thirty automobiles and trucks. Other data sets will be analysed in the future in this area. The next paper is by Geweke who studies the linear model under Student-*t* disturbances. It has long been argued in economics that the probability of extreme outcomes is larger than is assumed according to the normal law of errors, in particular, for financial time series. Geweke studies special features of the posterior and, using Gibbs sampling, constructs an algorithm where one generates random drawings from the posterior. His empirical analysis shows that, for the well known macro-economic time series of Nelson and Plosser (1982), the posterior odds favour Student-*t* disturbances over normally distributed disturbances. The paper by Kleibergen and Van Dijk considers the linear model with GARCH disturbances and with normal and Student-*t* disturbances. The authors study first the weak and quasi-strict stationarity properties of a Generalized Autoregressive Conditional Heteroscedastic (GARCH) model by analytical and simulation methods. Next, they perform a Bayesian analysis using a flat prior. In order to compute results they make use of importance sampling instead of Gibbs sampling. Their empirical results show that the assumption of Student-*t* disturbances is to be preferred over the assumption of normally distributed disturbances and that the step from normal to Student-*t* disturbances has more effect on results than the step from homoscedastic to GARCH disturbances.

The other papers in this volume can be classified under topics (ii) and (iii) mentioned above. In an original paper, Tony Smith develops a generalization of method of simulated moments and maximum likelihood to estimate parameters of non-linear dynamic econometric models. He makes use of a conditional density of the variables which corresponds to a vector autoregressive model with i.i.d. disturbances and with possibly many over identifying restrictions on the parameters. The computational method implies that one starts with choosing a set of structural parameters; simulates a vector time series from the structural model; fits a low order vector autoregressive model to the simulated series by least squares which yields parameter values which are then substituted in the quasi-likelihood. As a final step one maximizes this quasi-likelihood. The application deals with a real business cycle model where the structural restrictions are rejected. It is of considerable interest to compare Smith's approach with the calibration studies of real business cycle models.

Gourieroux, Monfort and Renault introduce the indirect inference methods which can be used for models whose likelihood function is intractable. The idea is to define an auxiliary criterion depending on the observable variables and on an auxiliary parameter, and to calibrate the structural parameter in order to minimize a distance between the estimators of the auxiliary parameter based on simulations from the structural model and based on the data. This class of methods is shown to provide consistent and asymptotically normal estimators and to contain as particular cases the simulated GMM method proposed by McFadden and the

extended simulated moment method proposed by Smith in this issue; moreover a version of the method generalizes the Gallant–Tauchen approach. Applications to the estimation of continuous time models provide very good results.

Laroque and Salanié study inference in non-linear dynamic econometric models with latent variables by making use of the simulated pseudo-maximum likelihood method. Their model allows for lagged endogenous variables, observed or latent, and for serial correlation in the disturbances. The computational method used dynamic simulations of the endogenous variables conditional upon values of the exogenous variables. Strong exogeneity is required for computational ease. Results for a small disequilibrium model are encouraging for the first order moments while more research is recommended for the estimation of standard errors in a numerically stable way. Future applications may include habit formation and errors in variables models.

Shephard studies the non-linear state space model and proposes an alternative to Kitagawa's numerical approach for the estimation and the smoothing problems. The approach is based on a Simulated EM Algorithm, i.e. on an EM algorithm in which the expectation step is replaced by approximation of the relevant conditional expectation based on simulations. These simulations must be done in the conditional distribution of the state vector given the observations and they are implemented through various versions of the Metropolis algorithm. The approach is applied to a stochastic variance model estimated from exchange rate data.

Danielsson and Richard are interested in the computation of the likelihood function of a dynamic model with unobservable endogenous variables. This function appears as a high-dimensional integral for which numerical methods fail. Instead the authors propose a method of sequentially optimized importance sampling. The importance sampler proposed is Gaussian but the procedure could be generalized to other samplers. The method is applied to a stochastic volatility model. On this example the variance reduction achieved is very important and accurate results can be obtained for integrals of size 2000.

The papers in this volume were presented at a conference on 'Econometric Inference using Simulation Techniques', held in Rotterdam, on 5 and 6, June 1992, and hosted by the Tinbergen Institute (TI). TI is the newly established joint research institute and graduate school of the faculties of economics of Erasmus University Rotterdam, the Free University in Amsterdam and the University of Amsterdam. More than thirty papers were presented in twelve main sessions and in a very lively poster session. Clearly, only a very small subset of the papers presented appear in the present volume. Some papers will appear in a later issue of this Journal, other papers will appear elsewhere or have simply served the very useful purpose of being a discussion paper of front line research. The organizers are grateful to the Tinbergen Institute, the Royal Netherlands Academy of Sciences, the Faculty of Economics of Erasmus University and the *Journal of Applied Econometrics* for organizational and financial support. The full conference programme was published in Volume 7 Supplement (1992) of this Journal.