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SPECIAL ISSUE ON ESTIMATION OF SIMULTANEOUS EQUATIONS SYSTEMS

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INTRODUCTION

BY EDWIN KUH

After many years of relative quiet, there is renewed interest in the estimation of systems of simultaneous equations. A decade ago, two-stage and three-stage least squares, particularly the former, appeared to meet most needs of the applied econometrics community. This issue of the *Annals* contains a number of important advances which shed new light on full system estimation. These advances build on prior work of James Brundy and Dale Jorgenson, on techniques of nonlinear simultaneous equation estimation, and on methods of modern numerical analysis. The availability of high-speed computers and the development of econometric software systems now make it possible to seriously contemplate using these computationally burdensome methods. Computer software and research capabilities at the NBER Computer Research Center should make a significant contribution in this regard.

The first paper in this collection—David Belsley's "Estimation of Systems of Simultaneous Equations, and Computational Specifications of GREMLIN"—is a comprehensive treatment of simultaneous equation estimation that is novel in two important respects. First, insofar as I am aware, it is the first systematic application of the methods of modern numerical analysis to problems of broad econometric interest. Second, it presents the design of GREMLIN, a comprehensive system of simultaneous equation estimation procedures that is now being programmed at the NBER Computer Research Center.[1]

Concerning numerical methods, Belsley shows that two well-established orthogonal matrix decompositions not only result in robust calculations in the presence of ill-conditioned matrices, but also economize on linear computations. These methods, the QR decomposition and the Singular Value decomposition, bring efficient numerical procedures to the attention of econometricians in readily understandable form.

The GREMLIN system will include the following estimators: general k-class, three-stage least squares (3SLS), instrumental variables, limited information and full information efficient instrumental variables (LIVE and FIVE), minimum distance, and full information maximum likelihood (FIML). When this system is completed in the fall of 1974, it will be the most comprehensive interactive system for estimating simultaneous equations which are both linear and nonlinear in parameters and variables.

There are close relationships between Jerry Hausman's paper on "Full Information Instrumental Variables Estimation of Simultaneous Equations Systems" and Brundy's and Jorgenson's on "The Relative Efficiency of

[1] GREMLIN stands for "Generalized Research Environment and Modeling Language for the Integrated Network". The "Integrated Network" refers to the telecommunications network by which NBER-affiliated researchers across the country can utilize GREMLIN and other systems developed by the Computer Research Center.

Instrumental Variables Estimators of Systems of Simultaneous Equations". Hausman, extending previous work, interprets three estimators in instrumental variables form—3SLS, FIVE, and FIML. The instrumental variables interpretation facilitates straightforward comparisons; in particular, it enables Hausman to demonstrate where the instrumental variables estimators, being less comprehensive, lose efficiency relative to FIML. Hausman also shows that the FIVE estimator is one iteration toward the FIML estimator and that iteration on FIVE estimates that converge result in FIML estimates.

Brundy and Jorgenson extend their earlier theoretical work on efficient instrumental variables estimators. The study presented here examines the computational aspects and relative efficiencies of their useful technique. Using Klein's Model I as a test vehicle, they find that the full information version, which forms mutually consistent estimates of both contemporaneous error covariances and the instruments in the given sample, is sufficiently more expensive than the limited information version that it may not be worth the differential efficiency gains. Hausman, also using Klein's Model I, finds that different methods yield rather different coefficient estimates, so that perhaps the method which fully utilizes all sample information is preferable. Thus, the choice of estimator remains an unresolved issue.

Finally, Brundy and Jorgenson conclude that the choice of instrumental variables in the initial estimation stage has little impact on the resulting coefficient estimates, and hence the main criterion for selecting the initial instrumental variables should be minimization of computation costs. The results both of Brundy and Jorgenson and of Hausman require linearity in the coefficients; neither estimation procedure recognizes autocorrelation in the errors.[2]

Unlike the preceding two papers, that of Jorgenson and Laffont on "Efficient Estimation of Nonlinear Simultaneous Equations with Additive Disturbances" and that of Berndt, Hall, Hall, and Hausman on "Estimation and Inference in Nonlinear Structural Models" represent intensive explorations into the statistical properties and estimation requirements of nonlinear simultaneous equations systems. As the authors are aware, their contributions require extensive tests using actual data and Monte Carlo methods in order to determine the computational feasibility and efficiency of their recommended procedures. Ample experience in econometrics and other fields indicates that high-order nonlinear estimation often does not converge and can be extremely expensive; and that convergence, when obtained, often occurs at a local minimum.

Jorgenson and Laffont, following Malinvaud, further develop the theory of best "consistent uniformly asymptotically normal" (CUAN) estimators for systems of nonlinear simultaneous equations with additive disturbances. Maximum likelihood is a Best CUAN estimator. In order to reduce computational costs associated with FIML, they build on the work of Amemiya, who proposed minimum distance or instrumental variables estimators instead of FIML. They show that the minimum distance and instrumental variables estimators are CUAN but not Best CUAN. The FIVE estimator developed for linear systems by Brundy

[2] FIVE has been extended to cover autocorrelation by Ray Fair, "Efficient Estimation of Simultaneous Equations with Autoregression Errors by Instrumental Variables" (*Econometrica*, Vol. LIV, No. 4 (November 1972), pps. 444–49). Hausman (*Econometrica*, forthcoming) treats the more general nonlinear case.

and Jorgenson turns out to be asymptotically equivalent to the minimum distance estimators in the nonlinear case. We are thus in a situation where maximum likelihood has the most desirable properties but is expensive and often difficult to compute.

The paper by Berndt and his colleagues combines theorems from modern numerical analysis with statistical properties of estimators to devise practical numerical estimation procedures. Nonlinear computation is a complex area that requires much art, trial and error, as well as applied mathematics. The authors' most significant contribution is to eliminate from Newton's method the need to construct a substantial number of third derivatives; they accomplish this by invoking the statistical theorem that "the variance-covariance matrix of a maximum likelihood *estimator* is equal to the variance-covariance matrix of the *gradient* of the likelihood function". They apply their suggested method to both maximum likelihood and minimum distance methods; in the latter case, they also rely on Amemiya's results that minimize a quadratic distance function containing instrumental variables (but no explicit Jacobian). This paper is a natural complement to that of Jorgenson and Laffont but differs importantly in that its primary concern is with a step-by-step development of a computational algorithm. Berndt and his colleagues also propose a one-step estimator which is best CUAN and thus has identical asymptotic properties with FIML. Once again, the proof of the pudding will be in actual testing and application to sizable problems.

In his paper "On the Robust Estimation of Econometric Models", Ray Fair applies methods of robust estimation that were developed at the NBER Computer Research Center, to his 11-equation, 61-parameter macroeconomic forecasting model. Robust estimators put less weight on extreme deviations than the usual minimization of some function of the sum of squared errors. One robust estimator, for example, minimizes the sum of absolute deviations; more complicated robust estimators put even less weight on the more extreme errors. These methods were originally developed for single-equation processes, and Fair has extended them to simultaneous equations. Using forecasting error as a criterion, he finds that the robust estimators, when compared with standard econometric procedures, markedly improve forecasting effectiveness. More theoretical work is necessary before we can be fully confident of the gains to be obtained from combining robust procedures with simultaneous equations estimators; in the meantime, Fair's work is an important reminder that current estimation theory is not the most appropriate approach for all applications to economic data.

This collection of papers sharpens our perceptions of many issues relating to the estimation of systems of simultaneous equations. As a result, difficult but much clearer agenda for further research have emerged. In essence, the tradeoff between computational feasibility and cost on the one hand, and statistical efficiency on the other, calls for intensive investigation. The GREMLIN system, now being developed at the NBER Computer Research Center, offers one promising environment for such research. And other research projects at the Center—in the areas of robust and ridge regression, time-varying parameter estimation, and numerical analysis—will interact with the work on simultaneous systems estimation and will perhaps contribute to the solution of problems articulated in the following pages.