Economics 551-B: ECONOMETRIC METHODS II

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CONTENT:

This course applies the probabilistic and limit-theoretic tools (WLLN, SLLN, CLT, etc.) presented in Economics 551-A to conduct inference in a wide class of econometric models. The course will focus on applications of econometric methods to substantive problems, although we will discuss a number general "philosophical" issues at various points in the course.

The first issue is whether one ought to use of Bayesian or Classical methods of inference. I will briefly cover Bayesian methods which have been revitalized given recent developments in monte carlo simulation and numerical integration. Nevertheless, Bayesian methods are still computationally burdensome and heavily linked to particular parametric functional forms, limiting their applicability to semi- and nonparametric problems (discussed further below). The primary focus of this course is on classical statistical inference using large-sample asymptotics to derive approximate sampling distributions of various estimators.

The second issue is whether one ought to use parametric, semi-parametric, or non-parametric estimation methods. The issue is best framed as a trade-off between efficient estimation under strong *a priori* assumptions about the underlying probabilistic structure (with a consequent risk that the estimator will be inconsistent if these assumptions are violated) versus consistent estimation under weak *a priori* assumptions (at the cost of slower rates of convergence and/or less efficient estimation of any particular probabilistic structure). I argue that we do not face an "all or nothing" choice between parametric and nonparametric methods, rather the problem is to select an appropriate method from an "estimation possibility" frontier depending on the strength of the prior assumptions we are willing to impose in any particular problem. A convenient way to trace out this frontier is via parametric "flexible functional forms" that are capable of approximating general probabilistic structures arbitrarily well as the number of parameters increases. Nonlinear regression using series approximations, neural networks with variable numbers of "hidden units", and "seive" methods where the parameter space increases at an appropriate rate with sample size such as maximum likelihood estimation based on Hermite series expansions about a Gaussian kernel are examples of this approach. In fact, we will show that these "flexible" methods are generally the only feasible way to go about non-parametric estimation since direct estimation by optimizing an estimation criterion over an infinite-dimensional space is generally an "ill-posed" problem. Nearly all of the "well-posed" methods rely on rules fixing the rate at which the dimension of the parameter space increases with sample size (or in the case of kernels and other smoothing methods, the rate at which "bandwidths" and other smoothing parameters tend to zero with sample size) or various penalty functions or other data-driven procedures for determining how many parameters to include in the estimation in order to avoid "overfitting" the data. In some sense these procedures are semi-automated methods for "specification searching", a procedure that has been discredited by Bayesian econometricians such as Edward Leamer. Paradoxically, it turns out that these sorts of specification searching procedures consistently identify the true model, whereas Bayesian methods run into serious difficulties in semi- and nonparametric contexts. Specifically, if the parameter space is infinite-dimensional the prior can completely overwhelm the data in the sense that the posterior distribution is not guaranteed to converge to a point mass at the true parameter value as the number of observations tends to infinity.

The final issue is whether one ought to be doing structural or reduced-form estimation of econometric models. I review the Haavelmo-Koopmans-Marschak-Lucas arguments for the use of structural econometric models that either have been derived from, or are consistent with, an underlying economic theory. These arguments show that structural models can be used to predict the effects of hypothetical policy or environmental changes, whereas reduced-form models are generally only capable of summarizing responses to existing or historical policy or environmental changes. On the other hand, structural models typically depend on strong, typically parametric *a priori* identifying assumptions whereas reduced-form models can employ semi and non-parametric estimation methods that require much weaker assumptions about the underlying structure. I discuss the identification problem and show that many commonly analyzed structural models are "non-parametrically unidentified" which implies that one generally cannot estimate structural models using fully non-parametric methods (although there are many cases where flexible parametric and semi-parametric methods can be used to estimate the structure). Where nonparametric methods can be useful is in specification testing, i.e. comparing the reduced-form of the structural model a nonparametric estimate of the reduced form. One possible way to resolve the identification problem is by integrating experimental and survey data. I will discuss this issue in the context of comparing structural vs. experimental predictions of the impact of job training programs.

I use Manski's (1988) "analogy principle" as an intuitive unifying concept motivating the main "classical" estimation methods. Examples of the approach include estimation of the population mean by the sample mean, or estimation of the population CDF by the sample CDF. The analogy principle is the best way to understand the seemingly bewildering array of econometric estimators most of which can be classified as extremum or *M-estimators* such as linear and nonlinear least squares, maximum likelihood, generalized method of moments, minimum distance, minimum chi-square, etc. We begin the course by reviewing the theory of parametric estimation and the fundamental efficiency bounds for unbiased least squares and maximum likelihood estimators, namely the Gauss-Markov and Cramer-Rao lower bounds. We also present extensions of the C-R bound to asymptotically-unbiased LAN estimators, Hájek's (1972) asymptotic local minimax bound, and briefly discuss Bahadur's (1960,1967) "large deviation" bounds. I then review results on the asymptotic equivalence of a number of different nonlinear estimators including method of moments, maximum likelihood, minimum distance, and minimum chi-square in the special case of multinomial distributions. Since multinomial distributions are dense in the space of all distributions, these results can be applied to derive Chamberlain's (1987,1992) efficiency bounds for semi-parametric estimators based on conditional moment restrictions. I complete the review of parametric estimation methods with a survey model specification tests including the standard "Holy Trinity", Chi-square, information-matrix, Hausman-Wu, and conditional moment tests. I briefly discuss issues of optimality and power of these tests, and the more difficult issues of sequential testing, model revision, and model selection. The literature on "model selection" serves as a bridge in moving from parametric to semi-parametric and non-parametric estimation methods. We cover several papers showing that there exist "automatic" rules for "specification searching" over an appropriately expanding family of parametric models will result in sequence of selected models that converges to an underlying "true" data generating process.

The second part of the course focuses on nonparametric estimation of density and regression functions using kernels, nearest neighbor methods, and various "sieve" estimation methods including splines, series approximations, and neural networks. I then turn to semiparametric models and flexible "seminonparametric" models that represent the middle ground between parametric and non-parametric estimation methods. Some of the semiparametric estimation methods are versions of *L-estimates* (linear combinations of order statistics) and *R-estimates* (estimates dervied from rank tests). In addition, some recent semi-parametric estimators are functionals of *U-statistics,* so I briefly review the relevant LLN's, CLT's, and the concept of projections of a U-statistic. In order to compare the relative efficiency of the various methods, I present the Begun-Hwang-Hall-Wellner generalized version of the Cramer-Rao lower bound for semiparametric models, and applications of this result to a variety of models. In certain problems the prior assumptions are so weak (such as the median independence assumption underlying Manski's maximum score estimator) that information for the parameteric component of the model is zero. This implies that a $\sqrt{N}$-consistent estimator does not exist. I review rate of convergence results for other non-parametric and semi-paramteric estimators delineating problems for which standard $\sqrt{N}$ rates are achievable, versus problems where convergence occurs at slower rates. In certain cases one can smooth discontinuous semi-parametric objective functions in such a way to guarantee consistency while still retaining $\sqrt{N}$ (or arbitrarily close to $\sqrt{N}$) convergence rates. Examples include Powell's (1984), (1986) work on LAD and quantile estimation of the censored regression model, and Horowitz's (1992) smoothed maximum score estimator.

The final methodological module focuses on simulation estimation, which has proven very useful for avoiding the computational burden of numerical integration that previoulsy prevented insurmountable obstacles to estimation of a number of econometric models. I review several different types of simulation estimators for discrete choice problems (where simulation is used to avoid high-dimensional numerical integrations required to compute choice probabilities with many alternatives) and macro/time-series applications. The simulation estimators include simulated maximum likelihood (SML), method of simulated momemts (MSM), and method of simulated scores (MSS), and the semi-parametric minimum distance estimator of Gallant and Tauchen. We review various types of simulators including crude frequency sampling as well as various types of "smoothed" probability estimators such as the Geweke-Hajivassiliou-Keane (GHK) method that has the advantage of yielding objective functions that are smooth functions of the model's parameters. We will also discuss the use of antithetic variates, acceptance/rejection, importance sampling, and Gibbs sampling methods (borrowed from the literature on Bayesian pattern recognition) to reduce noise and accelerate convergence of monte carlo methods.

The methodological principles outlined above will be illustrated in a variety of applied contexts:

- standard linear models, including models with censoring and truncation
- panel data and transition/duration models
- static and dynamic discrete/continuous choice models

GRADES:

The goal of this class is to introduce students to state-of-the art methods as well as unsolved problems at the frontiers of current research in econometrics. My philosophy is that the best way to learn these methods and to appreciate their problems and limitations is via "hands-on" applications. Thus, grades in this course will be based on: 1) periodic take home problems assigned during lectures (30% of grade), 2) a final exam (30% of grade) and 3) an original research paper (30 pages maximum) due at the scheduled final exam period for this course and a 15-30 minute in-class presentation describing the topic, the data, and the econometric methods to be used (40% of grade). Most students will choose applied topics involving actual estimation of a particular econometric model, although theoretically oriented papers are also welcome.

READINGS:

General Texts (recommended but not required)

Amemiya, T. (1985) *Advanced Econometrics* Harvard University Press.

Berndt, E.R. (1991) *The Practice of Econometrics: Classic and Contemporary* Addison Wesley.

Davidson, R. and J.G. MacKinnon (1996) *Estimation and Inference in Econometrics* Oxford University Press.

Manski, C.F. (1988) *Analog Estimation Methods in Econometrics* Chapman and Hall.

Poirier, D.J. (1995) *Intermediate Statistics and Econometrics: A Comparative Approach* MIT Press, Cambridge.

Rao, C.R. (1973) *Linear Statistical Inference and It's Applications* Wiley.

Serfling, R.J (1980) *Approximation Theorems of Mathematical Statistics* Wiley.

White, H. (1984) *Asymptotic Theory for Econometricians* Academic Press.

Overview of Methodological Debates in Econometrics

Granger, C.W.J. (1990) "Where are the Controversies in Econometric Methodology?" in C.W.J. Granger (ed.) *Modelling Economic Series* Oxsford Press.

Poirier, D.J. (1994) *The Methodology of Econometrics* (volumes 1 and 2) The International Library of Critical Writings in Econometrics, 6, Edward Elgar Publishers.

Bayesian vs. Classical Inference

DeGroot, M. (1970) *Optimal Statistical Decisions* McGraw-Hill, chapters 8,9.

Berger, J.O. (1985) *Statistical Decision Theory and Bayesian Analysis* Springer-Verlag, New York.

Hartigan, J.A. (1983) *Bayes Theory* Springer-Verlag, New York.

D. Lindley (1972) *Bayesian Statistics: A Review* SIAM Regional Conference Series in Applied Mathematics.

Zellner, A. (1971) *An Introduction to Bayesian Inference in Econometrics* Wiley.

Leamer, E. (1981) *Specification Searches* Wiley, chapters 1–4.

Leamer, E. (1983) “Let’s Take the Con out of Econometrics” *American Economic Review* 73, 31–43.

Leamer, E. (1992) “Bayesian Elicitation Diagnostics” *Econometrica* **60-4** 919-942.

Geman, S. and D. Geman (1984) “Stochastic Relaxation, Gibbs Distributions, and the Bayesian Restoration of Images” *IEEE Transactions on Pattern Analysis and Machine Intelligence* **6-6** 721–741.

Geweke, J. (1988) “Antithetic Acceleration of Monte Carlo Integration in Bayesian Inference” *Journal of Econometrics* **38** 73–90.

Geweke, J. (1989) “Bayesian Inference in Econometric Models Using Monte Carlo Integration” *Econometrica* **57-6** 1317–1341.

Geweke, J. (1992) “Bayesian Treatment of the Heteroscedastic and Independent Student-t Linear Models”, manuscript University of Minnesota.

Geweke, J. (1996) “Monte Carlo Simulation and Numerical Integration” in *Handbook of Computational Economics* H. Amman, D. Kendrick and J. Rust (eds.) Elsevier, North Holland.

McCulloch, R. and P. Rossi (1994) “An Exact Likelihood Approach to the Analysis of the MNP Model” *Journal of Econometrics* **64** 207–240.

Albert, J.H. and S. Chib (1993) “Bayesian Analysis of Binary and Polychotomous Response Data” *Journal of the American Statistical Association* **88** 669–679.

Gelfand, A.E. and A.F.M. Smith (1990) “Sampling Based Approaches to Calculating Marginal Densities” *Journal of the American Statistical Association* **85** 398–409.

Rossi, P. and R. McCulloch (1996) “The Value of Purchase History Data in Target Marketing” forthcoming, *Marketing Science*

Sims, C.A. (1988) “Bayesian Skepticism on Unit Root Econometrics” *Journal of Economic Dynamics and Control* **12** 463–474.

DeJong, D.N. and D.H. Whiteman (1991) “Trends and Random Walks in Macroeconomic Time Series: A Reconsideration Based on The Likelihood Principle” *Journal of Monetary Economics*

Phillips, P.C.B. (1991) “To Ciriticize the Critics: An Objective Bayesian Analysis of Stochastic Trends” *Journal of Applied Econometrics* **6** 333-364.

Phillips, P.C.B. “Bayesian Routes and Unit Roots: *de rebus prioribus semper est disputandum*” *Journal of Applied Econometrics* **6** 435-474.

Freedman, D. (1963) “On the Asymptotic Behavior of Bayes Estimates in the Discrete Case I” *Annals of Mathematical Statistics* **34** 1386–1403.

Diaconis, P. Freedman, D. (1986) “On the Consistency of Bayes Estimates” *Annals of Mathematical Statistics* **14** 1–26.

Chamberlain, G. and G. Imbens (1995) “Semiparametric Applications of Bayesian Inference” manuscript, Harvard University.

Diaconis, P. Freedman, D. (1990) “On the Uniform Consistency of Bayes Estimates for Multinomial Probabilities” *Annals of Statistics* **18-3** 1317–1327.

Johnson, R.A. (1970) “Asymptotic Expansions Associated with Posterior Distributions” *Annals of Mathematical Statistics* **41-3** 851–864.

Zellner, A. (1994) “Bayesian Method of Moments/Instrumental Variable (BMOM/IV) Analysis of Mean and Regression Models” manuscript, Graduate School of Business, University of Chicago.

Zellner, A. (1995) “Past and Recent Results on Maximal Data Information Priors” manuscript, Graduate School of Business, University of Chicago.

Zellner, A. and C. Min (1995) “Gibbs Sampler Convergence Criteria” *Journal of American Statistical Association* **90-431** 921–927.

Kadiyala, K. R. and S. Karlsson (1996) “Numerical Methods for Estimation and Inference in Bayesian VAR Models” forthcoming, *Jorunal of Applied Econometrics.*

Asymptotic Properties of M-Estimators

Newey, W.K. and D. McFadden (1994) “Large Sample Estimation and Hypothesis Testing” in D. McFadden and R. Engle (eds.) *Handbook of Econometrics* vol 4, Elsevier, Amsterdam.

Manski, C.F. (1994) “Analog Estimation of Econometric Models” in D. McFadden and R. Engle (eds.) *Handbook of Econometrics* vol 4, Elsevier, Amsterdam.

Rao, C.R. (1965) *Linear Statistical Inference and Its Applications* Wiley, chapters 4-7.

Prakasa Rao, B.L.S. (1987) *Asymtotic Theory of Statistical Inference* John Wiley & Sons.

Ibragimov, I.A. and R.Z. Khas’minskii (1981) *Statistical Estimation – Asymptotic Theory* Springer Verlag.

Le Cam, L. (1953) “On Some Asymptotic Properties of Maximum Likelihood Estimates and Related Bayes Estimates” *University of California Publications in Statistics* **1** 277-330.

Le Cam, L. (1970) “On the Assumptions Used to Prove Asymptotic Normality of Maximum Likelihood Estimates” *Annals of Statistics* **41-3** 802–828.

Le Cam, L. (1986) *Asymptotic Methods in Statistical Decision Theory* Springer-Verlag.

Le Cam, L. Yang, G.L. (1990) *Asymptotics in Statistics: Some Basic Concepts* Springer-Verlag.

Pfanzagl, J. (1982) *Contributions to a General Asymptotic Statistical Theory* Springer-Verlag.

Huber, P.J. (1967) "The Behavior of Maximum Likelihood Estimates under Non-Standard Conditions" in Proceedings of the the 5th Berkeley Symposium on Mathematical Statistics and Probability, University of California Press.

White, H. (1982) "Maximum Likelihood Estimation of Misspecified Models" *Econometrica* **50** 1–26.

Basawa, I.V. and B.L.S. Prakasa Rao (1980) *Statistical Inference for Stochastic Processes* Academic Press.

Billingsley, P. (1961) *Statistical Methods for Markov Processes* University of Chicago Press.

Crowder, M.J. (1976) "Maximum Likelihood Estimation for Dependent Observations" *Journal of Royal Statistical Society* Series **B 38** 45–53.

Kiefer, J. and J. Wolfowitz (1956) "Consistency of the Maximum Likelihood Estimator in the Presence of Infinitely Many Incidental Parameters" *Annals of Mathematical Statistics* **27** 887-906.

Bahadur, R.R. (1958) "Examples of Inconsistency of Maximum Likelihood Estimates" *Sankya* **20** 207–210.

Ruud, P.A. (1983) "Sufficient Conditions for the Consistency of Maximum Likelihood Estimation Despite Misspecification of Distribution" *Econometrica* **51** 225-228.

Guorieroux, C. Monfort, A. and A. Trognon (1984) "Psuedo Maximum Likelihood Methods: Theory" *Econometrica* **52** 681–700.

Cox, D.R. (1975) "Partial Likelihood" *Biometrika* **62** 269–276.

Burgete, J.F. A.R. Gallant, and G. Souza (1982) "On Unification of Asymptotic Theory of Nonlinear Econometric Models" *Econometric Reviews* **1** 151–190.

Newey, W. (1988) "Asymptotic Equivalence of Closest Moments and GMM Estimators" *Econometric Theory* **4** 336–340.

Bates, C. and White, H. (1985) "A Unified Theory of Consistent Estimation for Parametric Models" *Econometric Theory* **1** 151–178.

Hansen, L.P. (1982) "Large Sample Properties of Generalized Method of Moments Estimators" *Econometrica* **50** 1029–1054.

Gallant, A.R. Tauchen, G. (1992) "Which Moments to Match?" manuscript, North Carolina State University.

Amemiya, T. (1983) "Non-Linear Regression Models" in Z. Griliches and M.D. Intrilligator (eds.) *Handbook of Econometrics* vol 1, 333-389.

Manski, C.F. (1983) "Closest Empirical Distribution Estimation" *Econometrica* **51** 305–319.

Gallant, A.R. White, H. (1988) *A Unified Theory of Estimation and Inference for Nonlinear Dynamic Models* Basil Blackwell.

Wooldridge, J.M. (1994) "Estimation and Inference for Dependent Processes" in R. Engle and D. McFadden (eds.) *Handbook of Econometrics* volume 4, Elsevier, Amsterdam.

Jennrich, R.I. (1969) "Asymptotic Properties of Nonlinear Least Squares Estimators" *Annals of Mathematical Statistics* **40** 633-643.

Pötscher, B.M. and I.R. Prucha (1991) "Basic Structure of the Asymptotic Theory in Dynamic Nonlinear Econometric Models, Part I: Consistency and Approximation Concepts" *Econometric Reviews* **10** 125–216.

Pötscher, B.M. and I.R. Prucha (1991) "Basic Structure of the Asymptotic Theory in Dynamic Nonlinear Econometric Models, Part II: Asymptotic Normality" *Econometric Reviews* **10** 253–325.

White, H. (1982) "Instrumental Variables Regression with Independent Observations" *Econometrica* **50** 483–499.

Domowitz, I. and H. White (1982) "Misspecified Models with Dependent Observations" *Journal of Econometrics* **20** 35–58.

White, H. and I. Domowitz (1984) "Nonlinear Regression with Dependent Observations" *Econometrica* **52** 143–161.

Ferguson, T.S. (1958) "A Method of Generating Best Asymptotically Normal Estimates with an Application to the Estimation of Bacterial Densities"

Hypothesis and Specification Testing

Lehmann, E.L. (1959) *Testing Statistical Hypotheses* Wiley.

Godfrey, L.G. (1988) *Misspecification Tests in Econometrics: The Lagrange Principle and Other Approaches* Cambridge University Press.

Engle, R. (1984) "Wald, Likelihood Ratio and Lagrange Multiplier Tests in Econometrics" *Handbook of Econometrics* Volume 2, 775–826.

Gourieroux, C. and A. Monfort (1994) "Testing Non-Nested Hypotheses" in R. Engle and D. McFadden (eds.) *Handbook of Econometrics* volume 4, Elsevier, Amsterdam.

Andrews, D. (1988) "Chi-Square Diagnostic Tests for Econometric Models" *Journal of Econometrics* **37** 135–156.

Andrews, D. (1988) "Chi-Square Diagnostic Tests for Econometric Models: Theory" *Econometrica* **56** 1419–1453.

Breusch, T.S. and A.R. Pagan (1980) "The Lagrange Multiplier Test and its Applications to Model Specification in Econometrics" *Review of Economic Studies* XI VII 239–253.

Engle, R. (1982) "A General Approach to Lagrange Multiplier Model Diagnostics" *Journal of Econometrics* **20** 83–104.

Pagan, A. and A.D. Hall (1983) "Diagnostic Tests as Residual Analysis" *Econometric Reviews* **2** 159–218.

Bierens, H. (1990) "A Consistent Conditional Moment Test of Functional Form" *Econometrica* **58-6** 1443–1458.

White, H. (1987) "Specification Testing in Dynamic Models" in T. Bewley (ed.) *Advances in Econometrics* Cambridge University Press.

Hausman, J. (1978) "Specification Tests in Econometrics" *Econometrica* **46** 1251–1271.

Holly, A. (1982) "A Remark on Hausman's Specification Test" *Econometrica* **50** 749–759.

MacKinnon, J.G. (1983) "Model Specification Tests Against Non-Nested Alternatives" *Econometric Reviews* **2** 85–110.

Tauchen, G. (1985) "Diagnostic Testing and Evaluation of Maximum Likelihood Models" *Journal of Econometrics* **30** 415–443.

Newey, W.K. (1985) "Maximum Likelihood Specification Testing and Conditional Moment Tests" *Econometrica* **53** 1047–1070.

Newey, W.K. (1985) "Generalized Method of Moments Specification Testing" *Journal of Econometrics* **29** 229–256.

Ruud, P.A. (1984) "Tests of Specification in Econometrics" *Econometric Reviews* **3** 211–242.

Efficiency Bounds

Hàjek, J (1972) "Local Asymptotic Minimax and Admissibility in Estimation" in *Proceedings of the 6th Berkeley Symposium on Mathematical Statistics and Probability.*

Bahadur, R.R. (1971) *Some Limit Theorems in Statistics* SIAM Regional Conference Series in Applied Mathematics.

Bucklew, J.R. (1990) *Large Deviations Techniques in Decision, Simulation, and Estimation* Wiley, chapter 9.

Chamberlain, G. (1986) "Asymptotic Efficiency in Semi-Parametric Models with Censoring" *Journal of Econometrics* **32** 189–218.

Chamberlain, G. (1987) "Asymptotic Efficiency in Estimation with Conditional Moment Restrictions" *Journal of Econometrics* **34** 3-5–334.

Chamberlain, G. (1992) "Efficiency Bounds for Semiparametric Regression" *Econometrica* **60-3** 567–596.

Hansen, L.P. (1985) "A Method for Calculating Bounds on the Asymptotic Covariance Matrices of Generalized Method of Moments Estimators" *Journal of Econometrics* **30** 203–238.

Newey, W. (1990) "Semiparametric Efficiency Bounds" *Journal of Applied Econometrics* **5** 99-135.

Begun, J. W. Hall, W. Hwang, J. Wellner (1983) "Information and Asymptotic Efficiency in Parametric-NonParametric Models" *Annals of Statistics* **11** 432–452.

Levit, B. Ya. (1975) "On the Efficiency of a Class of Nonparametric Estimates" *Theory of Probability and its Applications* **20** 723–740.

Koshevnik, Yu. A. and B. Ya. Levit (1976) "On a Nonparametric Analogue of the Information Matrix" *Theory of Probability and Its Applications* **21** 738–753.

Cosslett, S.R. (1990) "Semi-Parametric Regression of a Regression Model with Sample Selectivity" in W. Barnett, J. Powell, and G. Tauchen (eds.) *Nonparametric and Semiparametric Methods Economics and Statistics* Cambridge University Press.

Cosslett, S.R. (1987) "Efficiency Bounds for Distribution-Free Estimators of the Binary Choice Model and the Censored Regression Model" *Econometrica* **55** 559–585.

Bickel, P. (1982) "On Adaptive Estimation" *Annals of Statistics* **10** 647–671.

Manski, C.F. (1984) "Adaptive Estimation of Nonlinear Regression Models" *Econometric Reviews* **3** 145–194.

Ritov, Y. and P. Bickel (1990) "Achieving Information Bounds in Non and Semi-parametric Models" *Annals of Statistics* **18** 925–938.

Robinson, P. (1987) "Asymptotically Efficient Estimation in the Presence of Heteroscedasticity of Unknown Form" *Econometrica* **55** 875–891.

Bickel, P. C.A.J. Klaasen, Y. Ritov, and J.A. Wellner (1989) *Efficient and Adaptive Inference in Semiparametric Models* Johns Hopkins University Press, forthcoming.

Severini, T.A. and W.H. Wong (1987) "Profile Likelihood and Semiparametric Models", manuscript, University of Chicago.

Schick, A. (1986) "On Asymptotically Efficient Estimation in Semiparametric Models" *Annals of Statistics* **14** 1139–1151.

Econometric Methods for Duration/Transition Data

Kalbfleisch, J.D. and Prentice, R.L. (1980) *The Statistical Analysis of Failure Time Data* Wiley.

Lancaster, T. (1990) *The Econometric Analysis of Transition Data* Cambridge University Press.

Lancaster, T. (1979) "Econometric Methods for the Duration of Unemployment" *Econometrica* **47-4** 939–956.

Tsiatis, A. (1981) "A Large Sample Study of Cox's Regression Model" *Annals of Statistics* **9** 93–108.

Han, A. and Hausman, J.A. (1990) "Specification and Semiparametric Estimation of Duration Models" *Journal of Applied Econometrics* **5** 1–28.

Elbers, C. and Ridder, G. (1982) "True and Spurious Duration Dependence: the Identifiability of the Proportional Hazards Model" *Review of Economic Studies* **49** 402–411.

Heckman, J.J. and Singer, B. (1984) "A Method for Minimizing the Impact of Distributional Assumptions in Econometric Models of Duration Data" *Econometrica* **52** 271–320.

Devine, T.J. and N.M. Kiefer (1990) *Empirical Labor Economics in the Search Framework* Cornell University Press.

Horowitz, J.L. and Ridder, G. (1992) "Semiparametric Estimation of a Regression Model with an Unknown Transformation of the Dependent Variable" manuscript, University of Iowa.

Parametric Estimation of Discrete Choice Models

McFadden, D. (1981) "Econometric Models of Probabilistic Choice" in C.F. Manski and D. McFadden (eds.) *Structural Analysis of Discrete Data with Econometric Applications* MIT Press.

McFadden, D. (1984) "Econometric Analysis of Qualitative Response Models" in Z. Griliches and M.D. Intrilligator (eds.) *Handbook of Econometrics* North Holland.

Hsieh, D. Manski, C.F. and D. McFadden (1985) "Estimation of Response Probabilities from Augmented Retrospective Observations" *Journal of the American Statistical Association* **80** 651–662.

Ruud, P. (1986) "Consistent Estimation of Limited Dependent Variable Models Despite Misspecification of Distribution" *Journal of Econometrics* **32** 157–187.

Ben-Akiva, M. and S. Lerman (1985) *Discrete Choice Analysis: Theory and Appilication to Travel Demand* MIT Press.

Train, K. (1986) *Qualitative Choice Analysis: Theory, Econometrics, and an Application* MIT Press.

Maddala, G.S. (1983) *Limited Dependent and Qualitative Variables in Econometrics* Cambridge University Press.

McCulloch, R. and P. Rossi (1994) "An Exact Likelihood Analysis of the Multinomial Probit Model" *Journal of Econometrics* **64-1** 207–240.

Geweke, J. Keane, M. and D. Runkle (1994) "Alternative Computational Approaches to Inference in the Multinomial Probit Model" *Review of Economics and Statistics* **76** 609–622.

Semiparametric Estimation of Discrete Choice Models and Related "Single Index" Models

Powell, J. (1995) "Estimation of Semiparametric Models" *Handbook of Econometrics* R.F. Engle and D.L. McFadden (eds.) North Holland, 2443–2514.

Robinson, P.M. (1988) "Semiparametric Econometrics: A Survey" *Journal of Applied Econometrics* **3** 35–51.

Manski, C.F. (1975) "Maximum Score Estimation of the Stochastic Utility Model of Choice" *Journal of Econometrics* **3** 205–228.

Manski, C.F. (1985) "Semiparametric Analysis of Discrete Response: Asymptotic Properties of the Maximum Score Estimator" *Journal of Econometrics* **27** 313–334.

Coppejans, M. (1995) "Estimation of the Binary Response Model with Dependent Observations" manuscript, Northwestern University.

Han, A.K. (1987) "Non-parametric Estimation of a Generalized Regression Model: The Maximum Rank Correlation Estimator" *Journal of Econometrics* **59** 35–61.

Klein, R. Spady, R.H. (1993) "An Efficient Semiparametric Estimator for Discrete Choice Models" *Econometrica* **61** 387–321.

Horowitz, J. (1992) "A Smoothed Maximum Score Estimator for the Binary Response Model" *Econometrica* **60-3** 505–532.

Cosslett, S.R. (1983) "Distribution-Free Maximum Likelihood Estimator of the Binary Choice Model" *Econometrica* **51** 765–782.

Kim, J. and D. Pollard (1990) "Cube Root Asymptotics" *Annals of Statistics* **18** 541–551.

Ichimura, H. (1988) "Semiparametric Least Squares (SLS) Estimation and Weighted SLS Estimation of Single Index Models" *Journal of Econometrics* **58** 71–120.

Stoker, T.M. (1986) "Consistent Estimation of Scaled Coefficients" *Econometrica* **54** 1461–1481.

Powell, J.H. J.H. Stock, and T.M. Stoker (1989) "Semiparametric Estimation of Index Coefficients" *Econometrica* **57-6** 1403–1430.

Hall, P. and H. Ichimura (1991) "Optimal Semiparametric Estimation of Single Index Models" manuscript, University of Minnesota.

Härdle, W. Hall, P. and H. Ichimura (1991) "Optimal Smoothing in Single Index Models" manuscript, University of Minnesota.

Horowitz, J. (1992) "Semiparametric and Nonparametric Estimation of Quantal Response Models" forthcoming, *Handbook of Statistics.*

Robinson, P. (1988) "Root-N Consistent Semiparametric Regression" *Econometrica* **56** 931–954.

Cosslett, S.R. (1991) "Semiparametric Estimation of a Regression Model with Sample Selectivity" in W.A. Barnett, J. Powell and G. Tauchen (eds.) *Nonparametric and Semiparametric Methods in Econometrics and Statistics* Cambridge University Press.

Robust Regression: L-Estimators and Regression Quantiles

Reiss R.D. (1989) *Approximate Distribution of Order Statistics* Springer Verlag.

Koenker, R. and Bassett, G. (1978) "Regression Quantiles" *Econometrica* **46** 33–50.

Ruppert, D. and Carroll, R.J. (1980) "Trimmed Least Squares Estimation in the Linear Model" *Journal of the American Statistical Association* **75** 828–838.

Koenker, R. and Bassett, G. (1982) "Robust Tests for Heteroscedasticity Based on Regression Quantiles" *Econometrica* **50** 43–61.

Basset, G. and Koenker, R. (1982) "An Empirical Quantile Function for Linear Models with *IID* Errors" *Journal of the American Statistical Association* **77** 407–415.

Powell, J.L. Least Absolute Deviations Estimation of the Censored Regression Model" *Journal of Econometrics* **32** 143–155.

Powell, J.L. (1986) "Censored Regression Quantiles" *Journal of Econometrics* **32** 143–155.

Powell, J.L. "Symmetrically Trimmed Least Squares Estimation of Tobit Models" *Econometrica* **54** 1435–1460.

Han, A.K. (1987) "Maximum Rank Correlation Estimator and Generalized Median Estimator in Censored Regression and Survival Models" *Journal of Econometrics* **35** 303–316.

Koenker, R. and Portnoy, S. (1987) "L-Estimation for the Linear Model" *Journal of the American Statistical Association* **82** 851–857.

Portnoy, S. and Koenker, R. (1989) "Adaptive L-estimation of Linear Models" *Annals of Statistics* **17** 362–381.

Chamberlain, G. (1990) "Quantile Regression, Censoring, and the Structure of Wages" in C.Sims (ed.) *Advances in Econometrics: Proceedings of the 6th World Congress of the Econometric Society*

Model Selection Procedures

Shao, J. (1994) "An Asymptotic Theory for Linear Model Selection" manuscript, Department of Mathematics, University of Otttawa.

Koenker, R. (1988) "Asymptotic Theory and Econometric Practice" *Journal of Applied Econometrics* **3** 139–147.

Pötscher, B.M. (1991) "Effects of Model Selection on Inference" *Econometric Theory* **7** 163–185.

Phillips, P.C.B. (1995) “Bayesian Model Selection and Prediction with Empirical Applications” *Journal of Econometrics* **69-1** 289–332.

Nonparametric Estimation Methods: Nearest Neighbor Estimation

Stone, C.J. (1977) “Consistent Nonparametric Regression” *Annals of Statistics* **5** 595–620.

Stone, C.J. (1980) “Optimal Rates of Convergence of Nonparametric Estimators” *Annals of Statistics* **8** 1348–1360.

Nonparametric Estimation Methods: Kernels

Härdle, W. and O. Linton (1994) “Applied Nonparametric Methods” in R. Engle and D. McFadden (eds.) *Handbook of Econometrics* volume 4, Elsevier, Amsterdam.

Collumb, G. (1985) “Nonparametric Regression: an Up-to-date Bibliography” *Statistics* **16** 309-324.

Silverman, B.W. (1986) *Density Estimation for Statistics and Data Analysis* New York, Chapman and Hall.

Tapia, R.A. and Thompson, J.R. (1978) *Nonparametric Probability Density Estimation* John Hopkins Press.

Devroye, L. and L. Györfi (1985) *Non-parametric Density Estimation: the L_1 View* Wiley, New York.

Härdle, W. (1990) *Applied Nonparametric Regression* Cambridge University Press.

Robinson, P.M. (1983) “Nonparametric Estimators for Time Series” *Journal of Time Series Analysis* **4** 185–207.

Bierens, H.J. (1987) “Kernel Estimation of Regression Functions” in T.F. Bewley (ed.) *Advances in Econometrics: Proceedings of the 5th World Congress of the Econometric Society* Cambridge University Press.

Devroye, L. and L. Györfi (1985) *Nonparametric Density Estimation: The L_1 View* Wiley.

Nonparametric Estimation Methods: Nonparametric Functional Estimation

Prakasa Rao, B.L.S. (1983) *Nonparametric Functional Estimation* Academic Press.

Van Der Vaart, A. (1991) “On Differentiable Functionals” *Annals of Statistics* **19-1** 178–204.

Newey, W. (1994) “Series Estimation of Regression Functionals” *Econometric Theory* **10** 1–28.

Gallant, A.R. and G. Souza (1990) “On the Asymptotic Normality of Fourier Flexible Form Estimates” manuscript, North Carolina State University.

Andrews, D.W.K. (1991) “Asymptotic Normality of Series Estimators for Nonparametric and Semiparametric Regression Models” *Econometrica* **59** 307–345.

Nonparametric Estimation Methods: Splines

Wahba, G. (1989) *Spline Models in Statistics* SIAM Regional Conference Series in Applied Mathematics.

Wahba, G. (1975) “A Completely Automatic French Curve: Fitting Spline Functions by Cross-Validation” *Communications in Statistics* **4** 1–17.

Friedman, J.H. (1991) “Multivariate Adaptive Regression Splines” *Annals of Statistics* **19-1** 1–141.

Cox, D.D. (1983) “Asymptotics for M-type Smoothing Splines” *Annals of Statistics* **11-2** 530–551.

Cox, D.D. (1984) “Multivariate Smoothing Spline Functions” *SIAM Journal of Numerical Analysis* **21-4** 789–813.

Eubank, R.L. (1988) *Spline Smoothing and Nonparametric Regression* New York, Marcel Dekker.

Nonparametric Estimation via Sieves, Series, Neural Nets other “Flexible Functional Forms”

Grenander, U. (1981) *Abstract Inference* Wiley.

Geman, S. and C. Hwang (1982) “Nonparametric Maximum Likelihood Estimation by the Method of Sieves” *Annals of Statistics* **10** 401-414.

Severini, T.A. and W.H. Wong (1987) “On Maximum Likelihood Estimation in Infinite-Dimensional Parameter Spaces” *Annals of Statistics* **19** 603–632.

Shen, X. and W.H. Wong (1994) “Convergence Rates for Sieve Estimates” *Annals of Statistics* **22** 580–615.

White, H. and Wooldridge, J.A. (1991) “Some Results on Sieve Estimators with Dependent Observations” in W.A. Barnett, J.L. Powell, G. Tauchen (eds.) *Nonparametric and Semiparametric Methods in Econometrics and Statistics.* Cambridge University Press.

Gallant, A.R. (1987) “Identification and Consistency in Seminonparametric Regression” in T. Bewley (ed.) *Advances in Econometrics* Proceedings of the 5th World Congress of the Econometric Society, Cambridge University Press.

Eastwood, B.J. and Gallant, A.R. (1990) “Adaptive Rules for Seminnonparametric Estimators that Achieve Asymptotic Normality”, manuscript, North Carolina State University.

Andrews, D.W.K. (1991) “Asymptotic Normality of Series Estimators for Nonparametric and Semiparametric Regression Models” *Econometrica* **59** 307–345.

Gallant, A.R. (1981) “On the Bias in Flexible Functional Forms and an Essentially Unbiased Form: The Fourier Flexible Form” *Journal of Econometrics* **15** 211–245.

Gallant, A. R. and D.W. Nychka (1989) “Seminonparametric Maximum Likelihood Estimation” *Econometrica* **55**, 363-390.

Gallant, A.R. and H. White (1992) “On Learning the Derivatives of an Unknown Mapping with Multilayer Feedforward Networks” *Neural Networks* **5** 129–138.

Gallant, A.R. and H. White (1988) “The Exists a Neural Network that Does Not Make Avoidable Mistakes” *Proceedings of the Second Annual IEEE Conference on Neural Networks* New York IEEE Press, 657–664.

White, H. (1990) “Connectionist Nonparametric Regression: Multilayer Feedforward Networks Can Learn Arbitrary Mappings” *Neural Networks* **3** 535–549.

Hornik, K. Stinchcombe, M. and H. White (1989) “Multilayer Feedforward Networks are Universal Approximators” *Neural Networks* **3** 551–560.

Yukich, J.E. M.B. Stinchcombe and H. White (1994) “Sup Norm Approximation Bounds for Networks through Probabilistic Methods” manuscript, University of California, San Diego.

Simulation Estimation

V.A. Hajivassiliou and P. Ruud (1994) "Classical Estimation Methods for LDV Models Using Simulation" in R. Engle and D. McFadden (eds.) *Handbook of Econometrics* vol. 4 Elsevier, Amsterdam.

Lerman, S. and C.F. Manski (1981) "On the Use of Simulated Frequencies to Approximate Choice Probabilities" in C.F. Manski and D. McFadden (eds.) *Structural Analysis of Discrete Data with Econometric Applications* MIT Press.

McFadden, D. (1991) "A Method of Simulated Moments for Estimation of Discrete Response Models without Numerical Integration" *Econometrica* **57-5** 995–1026.

Pakes, A. and Pollard, D. (1989) "Simulation and the Asymptotics of Simulation Estimators" *Econometrica* **57-5** 1027–1058.

Keane, M. (1994) "A Computationally Practical Simulation Estimator for Panel Data" *Econometrica* **62** 95–116.

Gourieroux, C. and A. Monfort (1993) "Simulation-based inference: A Survey with Special Reference to Panel Data Models" *Journal of Econometrics* **59** 5–33.

Hajivassiliou, V. McFadden, D. and P. Ruud (1991) "Simulation of Multivariate Normal Orthant Probabilities: Methods and Programs" working paper, Yale University.

Hajivassiliou, V. and D. McFadden (1990) "The Method of Simulated Scores for the Estimation of LDV Models with an Application to External Debt Crises" Cowles Discussion Paper 967.

Boersch-Supan, A. and V. Hajivassiliou (1990) "Smooth, Unbiased Multivariate Probability Simulators for Maximum Likelihood Estimation of Limited Dependent Variable Models" Cowles Foundation Paper 960.

Stern, S. (1992) "A method for Smoothing Simulated Moments of Discrete Probabilities in Multinomial Probit Models" **60-4** 943–952.

Duffie, D. and K. Singleton (1989) "Simulated Moments Estimation of Markov Models of Asset Prices" manuscript, Stanford University.

Ingram, B. and B. Lee (1991) "Estimation by Simulation" *Journal of Econometrics*

Danielsson, J. (1992) "Stochastic Volatility in Asset Prices: Estimation with Simulated Maximum Likelihood" manuscript, Universit of Iceland.

Lee, L.F. (1996) "Simulated Maximum Likelihood Estimation of Dynamic Discrete Choice Statistical Models — Some Monte Carlo Results" forthcoming, *Journal of Econometrics.*

Econometric Models for Count Data

Hausman, J. Hall, B.H. and Z. Grliches (1984) "Econometric Models for Count Data with an Application to the Patents-R&D Relationship" *Econometrica* **52-4** 909–938.

Mullahy, J. (1986) "Specification and Testing of Some Modified Count Data Models" *Journal of Econometrics* **33** 341–365.

Cameron, A.C. and P.K. Trivedi (1986) "Econometric Models Based on Count Data: Comparisons and Applications of Some Estimators" *Journal of Applied Econometrics* **1** 29–53.

Gurmu, S. Rilstone, P. and S. Stern (1995) "Semiparametric Estimation of Count Regression Models" manuscript, Department of Economics, University of Virginia.

Econometric Methods for Panel Data

Hsiao, C. (1986) *Analysis of Panel Data* Cambridge University Press.

Balestra, P. and M. Nerlove (1966) "Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas" *Econometrica* **34-3** 585–612.

Wallace, T.D. and A. Hussein (1969) "The Use of Error Components Models in Combining Cross Section with Time Series Data" *Econometrica* **37-1** 55–72.

Mundlak, Y. (1978) "On the Pooling of Time Series and Cross Section Data" *Econometrica* **46** 69–86.

Maddala, G.S. (1971) "The Use of Variance Components Models in Pooling Cross Section and Time Series Data" *Econometrica* **39-2** 341–358.

Hausman, J.A. and W.E. Taylor (1981) "Panel Data and Unobservable Individual Effects" *Econometrica* **49** 1377–1398.

Breusch, T.S. (1987) "Maximum Likelihood Estimation of Random Effects Models" *Journal of Econometrics* **36-3** 383–389.

Chamberlain, G. (1980) "Analysis of Covariance with Qualitative Data" *Review of Economic Studies* XLVII, 225–237.

Manski, C.F. (1987) "Semiparametric Analysis of Random Effects Linear Models from Binary Panel Data" *Econometrica* **55** 357–362.

Honoré, B.E. (1992) "Trimmed LAD and Least Squares Estimation of Truncated and Censored Regression Models with Fixed Effects" *Econometrica* **60-3** 533-566.

Honoré, B.E. (1993) "Orthogonality Conditions for Tobit Models with Fixed Effects and Lagged Dependent Variables" *Journal of Econometrics* **59** 35–61.

Chamberlain, G. (1982) "Multivariate Regression Models for Panel Data" *Journal of Econometrics* **18** 5–46.

Chamberlain, G. (1984) "Panel Data" in Z. Griliches and M.D. Intrilligator (eds.) *Handbook of Econometrics* volume 2, North Holland, 1247–1318.

Bhargava, A. and J.D. Sargan (1983) "Estimating Dynamic Random Effects Models from Panel Data Covering Short Time Periods" *Econometrica* **51** 1635–1659.

Amemiya, T. and T. MaCurdy (1986) "Instrumental Variables Estimation of an Error Component Model" *Econometrica* **54** 869–881.

Breusch, T.S. G.E. Mizon, and P. Schmidt (1989) "Efficient Estimation Using Panel Data" *Econometrica* **57** 695–701.

Holtz-Eakin, D. Newey, W. and H.S. Rosen (1988) "Estimating Vector Autogressions with Panel Data" *Econmetrica* 1371–1396.

Ahn, S.C. and P. Schmidt (1995) "Efficient Estimation of Models for Dynamic Panel Data" *Journal of Econometrics* **68-1** 5–28.

Ahn, S.C. and P. Schmidt (1992) "Efficient Estimation of Panel Data Models with Exogenous and Lagged Dependent Regressors" manuscript, University of Michigan.

Keane, M.P. and D.E. Runkle (1992) “On the Estimation of Panel Data Models with Serial Correlation when Instruments are not Strictly Exogenous” *Journal of Business and Economic Statistics* **10** 1–19.

Issues in Structural vs. Reduced-form Inference and Prediction the Role of Experiments

Haavelmo, Trygve (1944) “The Probability Approach in Econometrics” *Econometrica* **12** 1–115.

Marschak, J. (1953) “Economic Measurements for Policy and Prediction” in W.C. Hood and T.C. Koopmans (eds.) *Studies in Econometric Method* Cowles Commission Monograph 13, Wiley.

Lucas, R.E. Jr. (1976) “Econometric Policy Evaluation: A Critique” in K. Brunner and A.K Meltzer (eds.) *The Phillips Curve and Labour Markets* Carnegie-Rohcester Conference on Public Policy, North Holland (also reprinted in *Studies in Business Cycle Theory* MIT Press, 1981.

Heckman, J.J. (1992) “Randomization and Social Policy Evaluation” in C.F. Manski and I. Garfinkel (eds.) *Evaluating Welfare and Training Programs* Harvard University Press, Cambridge, 201–230.

Heckman, J.J. (1990) “Alternative Approaches to the Evaluation of Social Programs: Econometric and Experimental Methods” forthcoming in J. Laffont and C. Sims (eds.) *Advances in Econometrics: Sixth World Congress* Econometric Society Monographs, Cambridge University Press.

LaLonde, R. (1986) “Evaluating the Econometric Evaluations of Training Programs with Experimental Data” *American Economic Review* **76** 604–620.

Estimation of Dynamic Discrete Choice Models

Rust, J. (1994) “Estimation of Dynamic Structural Models: Problems and Prospects Part I: Discrete Decision Processes” in *Advances in Econometrics: Proceedings of the 6th World Congress of the Econometric Society* C. Sims, J.J. Laffont (eds.) Cambridge University Press.

Pakes, A. (1994) “Estimation of Dynamic Structural Models: Problems and Prospects Part II: Mixed Continuous–Discrete Models and Market Interactions” in *Advances in Econometrics: Proceedings of 6th World Congress of the Econometric Society* C. Sims, J.J. Laffont, (eds.) ambridge University Press.

Rust, J. (1994) “Structural Estimation of Markov Decision Processes” in R. Engle and D. McFadden (eds.) *Handbook of Econometrics* Volume 4, 3082-3139. North Holland.

Rust, J. (1988) “Maximum Likelihood Estimation of Discrete Control Processes” *SIAM Journal on Control and Optimization* 26-5, 1006-1023.

Rust, J. (1987) “Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher” *Econometrica* 55-5, 999-1033.

Pakes, A. (1986) “Patents as Options: Some Estimates of the Value of Holding European Patent Stocks” *Econometrica* 54 755-785.

Wolpin, K.I. (1987) “Estimating a Structural Search Model: The Transition from School to Work” *Econometrica* **55,** 801–818.

Lancaster, T. (1996) “Exact Structural Inference in Optimal Job Search Models” forthcoming, *Journal of Business and Economic Statistics.*

Wolpin, K. (1984) “An Estimable Dynamic Stochastic Model of Fertility and Child Mortality” *Journal of Political Economy* 92-5, 852-874.

Das, M. (1992) “A Micro Econometric Model of Capital Utilization and Retirement: The Case of the Cement Industry” *Review of Economic Studies* **59-2** 277–298.

Hotz, V. and R. Miller (1993) “Conditional Choice Probabilities and the Estimation of Dynamic Programming Models” *Review of Economic Studies* **60** 497–530.

Hotz, V. Miller, R. Sanders, S. and J. Smith (1993) “A Simulation Estimator for Dynamic Models of Discrete Choice” *Review of Economic Studies* **60** 397–429.

Geweke, J. and M. Keane (1996) “Bayesian Inference for Dynamic Discrete Choice Models without the Need for Dynamic Programming” working paper 564, Research Department, Federal Reserve Bank of Minneapolis.