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BOOK REVIEWS

ECONOMETRIC THEORY

by James Davidson
Blackwell Publishers, 2000

REVIEWED BY
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1. INTRODUCTION

Professor Davidson's *Econometric Theory* offers a clear, well written, graduate level econometrics textbook, which would be highly appropriate as the principal text for the second and/or third semester of a general Ph.D. econometrics sequence or for a specialized course on time series. It provides good reading material for anyone interested in deepening his or her understanding of econometrics and also a valuable reference source for econometricians. Although the book reviews the basics of multivariate regression, it is written at a level that requires either some degree of mathematical sophistication or prior familiarity with econometrics. As a result, it may be too advanced for a first semester Ph.D. course, except where students have strong preparation.

The text provides the reader with a deep understanding of many of the principal concepts and estimation techniques used in econometrics. It can also be seen as providing a bridge between econometric theory and practical econometric methodology. Although all the coverage is devoted to modern econometric procedures widely used in practice, the book takes "the probabilistic foundations of the subject seriously." Although, the text does not attempt to tackle the derivation of high level probability results, such as laws of large numbers and central limit theorems for heterogenous and dependent data, these results are stated and explicitly referred to when deriving the behavior of standard estimators. Along these lines, there is also a rigorous and unified treatment of the asymptotic theory for optimization estimators, which helps greatly to simplify the individual estimation techniques, such as maximum likelihood, the general method of moments, and nonlinear least squares (NLS). Similarly, treating the regressors as explicitly random from the outset and emphasizing conditional expectations helps to provide a more cohesive treatment of linear models. For example, instrumental variables and time series regression are more easily cov-

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ered if students are already comfortable with random regressors. Additional themes emphasized in the text include exogeneity and model specification, partially specified models, and the pseudo–maximum likelihood interpretation of optimization estimators.

In writing the book, the author himself acknowledges an explicit preference for depth over breadth of coverage. Although the text in fact covers quite a wide range of material, no attempt is made to be all inclusive. The text is strictly classical in its approach, with virtually no mention of Bayesian approaches to econometrics. It does, however, give fairly thorough coverage to most of the classical econometric techniques that might be expected in a basic graduate course on econometrics. The more advanced coverage, of which there is quite a bit, is primarily weighted toward time series. In fact, two of the four sections in the book are explicitly devoted to time series techniques. This makes the text suitable for an econometrics course with a macro or finance orientation but leaves out some other important topics in econometrics, such as simulation estimators, the bootstrap, nonparametric techniques, and panel data methods.

In addition to providing a high-level introduction to econometrics, the text could also be used for a one-semester introduction to time series econometrics. Section 2 provides several chapters on stationary time series, including dynamic modeling, exogeneity and causation, stationary asymptotics for dynamic and vector autoregression (VAR), and simultaneous equations. Section 3 includes some material on autoregressive conditional heteroskedasticity (ARCH) and generalized autoregressive conditional heteroskedasticity (GARCH), and Section 4 provides a fairly rigorous introduction to unit roots and cointegration. Here too, there is slightly more emphasis on depth, rather than on breadth, of coverage. A few topics that are not covered, but might be supplemented elsewhere, include spectral domain analysis, forecasting, regime shifts, and long memory. Although the VAR framework is adopted frequently throughout the text, given its central role in (noncalibrated) empirical macroeconomics, an explicit chapter or section devoted to practical VAR methodology might have been helpful. Particular topics where the author's carefully reasoned approach would have been useful include (i) estimation and inference in a VAR with long-run identifying restrictions (such as the long-run neutrality of money), (ii) estimation and inference on impulse response functions, and (iii) the effect of running a VAR in either levels or differences when there are some unit roots and/or cointegrating relations.

The book is organized into four sections. The first section reviews the classical linear regression. The second section covers stationary time series. The third section focuses on optimization estimators, and the fourth covers unit roots and cointegration. A useful set of appendixes reviews matrix algebra, probability (using measure theoretic concepts), and the Gaussian distribution and its relatives. The end of each chapter contains a helpful paragraph pointing the reader to specific references on each of the subjects listed. Davidson is also particularly good in giving credit where it is due, making every attempt to cite

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the original contribution even for results that are several decades old. For students or readers with an interest in pursuing the theoretical side of econometrics there are also many useful references to the author's advanced text on stochastic limit theory (Davidson, 1994). In fact the two books work quite well together. All this should be helpful in encouraging students to make the transition from course work to research. Unfortunately, one important shortcoming that must be mentioned from a pedagogical perspective is that there are no problems or exercises included. With use of the Internet this drawback could conceivably be rectified.

2. A CHAPTER BY CHAPTER ANALYSIS

Section I (Chapters 1–3) covers linear regression. The first chapter provides a mature introduction to the least squares regression model. It includes clear, concise coverage of most standard topics (including least squares estimation, goodness of fit, partitioned regression, the Frisch–Waugh theorem, projection matrices, and linear transformation of the regression). There is also a careful discussion of the three model assumptions for the explanatory variables: fixed in repeated samples, independent random variables, and time series regressors. The linear regression is then properly presented as a model of the conditional expectation (of y given x). Another strong point is the early introduction of model selection issues. The chapter includes a useful discussion of the appropriate choice of left- and right-hand-side variables, complemented by an analysis of regression with relevant regressors omitted. In the same spirit, it discusses the role of the linear model as a local approximation to possibly nonlinear relationships. Missing from this chapter are both the geometric and the line of best fit interpretation of least squares (no figures are included).

Chapter 2 develops the finite sample statistical properties of the ordinary least squares estimator (OLS) under independence and normality. Particular topics addressed include properties of the OLS estimator, the Gauss–Markov theorem, near multicollinearity, generalized least squares (GLS), t- and F-tests, confidence regions, and prediction. All the results are derived under the random regressor assumption, allowing for greater realism and encouraging familiarity with the law of iterative expectations. Some interesting examples also help to motivate the material. For instance, the analysis of GLS is preceded by an example in which randomly varying regression coefficients lead to heteroskedastic regression residuals. Another interesting example given is the Nerlove (1963) study of cost functions, in which spurious detection of autocorrelation was found to arise from the omission of quadratic terms in the regression.

Chapter 3 provides a rigorous, yet accessible, presentation of the asymptotic theory for regression with independent data. It introduces the reader to the relevant large sample concepts from both probability theory (almost sure [a.s.], in probability, mean-squared, and weak convergence) and statistics (consistency, asymptotic normality, and asymptotic efficiency), gives a detailed presentation

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of laws of large numbers (LLNs) and central limit theorems (CLTs) for independent but heterogeneous data, and outlines the basic rules for working with these results (the Slutsky theorem, Cramér's theorem, the continuous mapping theorem, and the Cramér–Wold device). This careful development then allows for easy application to large sample theory for regression and instrumental variables. The chapter has several particularly attractive aspects. First, the detailed presentation of the large sample theory for heterogeneous processes makes the limit theory for regression very clear (after all, $x_i \varepsilon_i$ is heterogeneous, even if ε_i is independent and identically distributed [i.i.d.]). Second, it includes an illuminating discussion of the often obscure $1 + \delta$ and $2 + \delta$ moment conditions that typically accompany LLNs and CLTs, providing counterexamples to explain what can go wrong when they are violated. Finally, by pointing the interested reader to his advanced text (Davidson, 1994), the author is able to present sophisticated results without either omitting proofs or being forced into a large digression on probability theory. Arguably, however, a heuristic derivation of the CLT for even the simplest i.i.d. case would still have been useful.

Section II (Chapters 4–8) covers stationary times series modeling, including instrumental variables and simultaneous equations. Chapter 4 contains three distinct parts. By working through the VAR(1), it begins with a hands-on introduction to dynamic modeling, addressing topics such as the structural and reduced form VAR and construction of the likelihood. While avoiding the tedium of plowing through the full VAR(k) case, we learn how to write the VAR(k) in companion form and solve for its stability condition. The second part of Chapter 4 provides a short introduction to the concepts of stationarity, mixing, and ergodicity, together with a statement of the ergodic theorem. The final portion of Chapter 4 then discusses the concepts of marginalization, conditioning, and exogeneity, with much of the discussion following Engle, Hendry, and Richard (1983). Exogeneity conditions are appropriately introduced as conditions under which reduced form parameters can be given a structural interpretation, and some useful illustrations are provided using a bivariate VAR(1). However, given the key role of the structural model, the examples might have been improved had they been given some economic content. Even in an advanced text, a quick supply and demand curve illustration could go a long way in building student intuition.

The primary focus of the fifth chapter is on stationary dynamic models. It begins with a clear presentation of lag operators and polynomials, with application to autoregressive moving average (ARMA), autoregressive integrated moving average (ARIMA), and VAR models, and a short discussion of the Wold decomposition and linear processes. The remainder of the chapter is dedicated to dynamic regression models, with extensive coverage of the ARMA distributed lag model, the error correction representation, and models with forward looking expectations on the right-hand side. The text also makes a point of introducing several economic models that provide intuition for why lag structures are generally found necessary in time series regression. These include heuristic approaches, such as partial adjustment and adaptive expectation models,

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and also models based on dynamic optimization. Admittedly, the modelling is a bit superficial (and perhaps old fashioned) compared to what might be found in a graduate macro text. Nevertheless, the emphasis on linking statistical time series models to models of economic behavior seems especially welcome, particularly given the recent hand-wringing of some distinguished members of the profession (e.g., Heckman, 2001) over the growing divide between economics and econometrics.

Chapter 6 extends the asymptotic theory of Chapter 3 to the time series context. CLTs and LLNs are stated for both martingale difference sequences (MDS) and serially correlated time series. A straightforward application of these results to the simple stationary AR(1) model (both correctly specified and misspecified) demonstrates how these theorems can be employed in practice and their conditions verified. The slightly abstract concepts involved (i.e., mixing, near-epoch dependence, MDS) are not only clearly explained but also well motivated. For example, the chapter contains an interesting discussion of the shortcomings of the mixing conditions approach that led to the adoption of near-epoch dependence. Helping to provide a link with later chapters on unit roots and cointegration, it also develops an approximation to the finite sample bias in the autoregressive estimate first discussed by Hurwitz (1950). In a course segment focused on asymptotic theory, this chapter fits together nicely with Chapter 3, Section 4.4, and the first half of Chapter 7. Together with Davidson (1994) they also provide a particularly useful reference for econometricians. If anything is missing from these chapters, it is a chance for the students to work through the heuristics of the LLNs and CLTs themselves. An additional lecture (or two) on the Phillips and Solo (1992) linear process approach to proving LLNs and CLTs for dependent processes would provide a useful way to fill this gap. These proofs require less in the way of probabilistic sophistication and should be accessible to students at this level.

Chapter 7 consists of two parts. The first half extends the analysis of Chapter 6 to provide asymptotics for dynamic regression models, whereas the second half addresses the practical issues of model selection and diagnostic testing. A rigorous development of the asymptotic theory for dynamic regression with MDS errors (under various assumptions) provides the reader with a great deal of practice in applying the LLNs and CLTs of Chapter 6. The accompanying discussion of asymptotics for regression with trends and dummy variables also seems quite well done. In addition to the standard coverage, the text discusses the subtleties involving the case in which several regressors share the same trend and also the conceptual difficulty in applying asymptotic analysis to intervention dummies. The second half of the chapter then provides a clear, practical discussion of model building and selection issues, including general to specific modeling, sequential testing, data mining, and diagnostic tests for residual autocorrelation, conditional heteroskedasticity, nonnormality, and parameter stability. Perhaps regrettably, model selection procedures (e.g., Bayesian information criterion [BIC], posterior information criterion [PIC], Akaike information criterion [AIC]), receive virtually no men-

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tion at this point, having been reserved almost exclusively for later discussion in Section 9.4.1.

The author draws a link between the two parts of Chapter 7 by stressing that proper model selection techniques (part 2) are needed to reduce the residuals to MDSs, to apply the asymptotic theory for dynamic regression (part 1). Given the (unused) CLTs for dependent processes presented in chapter 6, this might leave the reader slightly confused. The principal problem with serially correlated errors would seem not to be the lack of a CLT for dependent data but rather a concern over endogeneity issues arising from correlation with lag dependent variables. Perhaps a better way of motivating the importance of model selection procedures would have been to point out that stronger (and often unrealistic) exogeneity assumptions are typically required when the residuals are serially correlated. In this respect, the material on model building would also fit well with discussion of exogeneity in Chapter 4.

Chapter 8 provides a thorough development of instrumental variables (IV), two stage least squares (2SLS), and Hausman-type tests for exogeneity. Particular time and effort are spent addressing the identification conditions, such as the rank and order conditions, and the analysis is also extended to nonlinear (in variables) simultaneous equations. This chapter is one of the many places where the emphasis on stochastic regressors and conditional expectations pays off handsomely, by helping to clarify the analysis and simplify the presentation. For example consider the IV specification $y_t = x_t'\beta + u_t$, $E(u|I_t) = 0$, where $E[z_t x_t']$ is invertible and the instrument z_t, but not the regressor x_t, is included in the information set I_t. Simply noting that $E[x_t u_t] \neq 0$, $\beta = E[x_t x_t']^{-1}(E[x_t y_t] - E[x_t u_t]) \neq E[x_t x_t']^{-1}E[x_t y_t] = p\lim \hat{\beta}_{OLS}$, and $\beta = E[z_t x_t']^{-1}E[z_t y_t] = p\lim \hat{\beta}_{IV}$ clearly illustrates both the inconsistency of the least squares estimator $\hat{\beta}_{OLS}$ and the consistency of the IV estimator $\hat{\beta}_{IV}$. Nevertheless, as is often the case with these topics, the reader is still required to keep track of a fair bit of notation, and although some interesting examples are provided, further discussion of the practical task of finding good instruments might also have been useful.

Section III (Chapters 9–13) is devoted to optimization estimators. Chapter 9 introduces the reader to this topic. The first half of the chapter provides a thorough guide to numerical optimization, covering several variants of both derivative based methods (e.g., Newton and quasi-Newton methods) and direct search methods (e.g., conjugate directions). Also of practical interest is a discussion of what can go wrong during search methods (e.g., "flats" and local minima), numerical approximation to first and second derivatives, and a brief discussion of software. This provides a valuable reference, helping the reader both to program his or her own search methods and to "look under the hood" of commonly available prepackaged routines. The remainder of the chapter covers the asymptotic properties of optimization estimation, along with a discussion of model selection rules, two-step estimation, and covariance estimation. In addition to the standard textbook coverage (e.g., existence, identification, consistency, and asymptotic normality), this section also discusses some of the more sophisticated results from this literature. For example, it introduces the concept

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of stochastic equicontinuity and, following Andrews (1987), shows how this can be used to guarantee that the criterion function converges uniformly.

After the main theoretical results for optimization estimators have been derived in Chapter 9, Chapter 10 then introduces the reader to a host of interesting and important examples, including nonlinear least squares, general method of moments (GMM), error correction models, variance estimation, and regression with autoregressive and conditionally heteroskedastic errors. Davidson works through the examples quite carefully, discussing in detail how to apply the numerical optimization procedures and asymptotic theory of the previous chapter to these particular cases. If there is any room to improve upon this chapter, it would perhaps be on the coverage of GMM. In particular, the text does not seem to fully convey a sense of just how generally applicable an estimation technique it is. This may be partly a result of the fact that the GMM estimator is presented as a nonlinear IV estimator. The more common approach to teaching this material, which emphasizes the matching of sample to population moments and then introduces the weight matrix in the overidentified case, may prove somewhat more intuitive to the uninitiated reader.

Chapter 11 covers maximum likelihood (ML). It begins by working though several examples, including Gaussian regression, autoregression, dynamic regression, and the logit, probit, and Tobit models. Making use of the results of Chapter 9, it then addresses the asymptotic theory (Kullback–Leibler information, identification, consistency, asymptotic normality, the information matrix equality, and the Cramér–Rao lower bound). The asymptotic analysis is carried out in a general framework, without requiring independence or homogeneity, and there is a brief discussion of how the results could be extended to cover discrete and mixed distributions. A particular strength of the chapter is its emphasis on the concept of quasi–maximum likelihood (quasi-ML) estimation, distinguishing cases in which the ML estimator can be justified in more general settings (e.g., Gaussian regression) from those in which the properties of the ML estimator depend to a larger extent on the distributional assumptions of the model (e.g., logit and probit).

Chapter 12 is dedicated to hypothesis testing. Along with the three classic likelihood based tests (likelihood ratio, Wald, and Score) considerable attention is given to two other testing strategies widely employed in econometrics, the Durbin–Wu–Hausman principle, involving the comparison of the constrained and unconstrained estimators, and the *M*-tests of Newey (1985) and Tauchen (1985). Continuing the emphasis on quasi-ML, these tests are presented in the more general context of optimization estimators wherever possible. The distributions of the tests are derived both under the null and, following a discussion of the Pitman drift, under the local alternative. Several applications, including tests for residual autocorrelation and heteroskedasticity, tests of functional form, and the White (1980) information test, not only help to provide useful illustrations but are also of interest in their own right.

Chapter 13 covers system estimation of simultaneous regression. Included are standard topics, such as three stage least squares (3SLS), full and limited

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information maximum likelihood (FIML and LIML), and seemingly unrelated regression (SUR), in addition to extensive coverage of more advanced topics, such as the estimation of nonlinear systems. This chapter does a nice job of highlighting the trade-off between efficiency and robustness in moving from LIML to FIML. In this context, it also discusses the estimation of partial systems in which the specifications of some, but not all, of the equations are trusted (i.e., a halfway house between LIML and FIML). Despite substantial notation and matrix algebra the development is quite lucid, and there are many useful insights to be had from even a cursory read. Perhaps one small pedagogical improvement would have been to build up to 3SLS (really a combination of 2SLS and SUR) by covering SUR first, rather than simply treating SUR as a special case of 3SLS.

Section IV (Chapters 14–16), the final section, covers unit roots and cointegration. Chapter 14 provides a well written and easy to follow introduction to univariate unit root asymptotics and testing. Although explicit proofs of the more technical results, such as the functional CLT, are omitted, the chapter gives careful coverage to the central concepts and algebra required to understand this area of econometrics. Bridging the gap between unit root and stationary asymptotics, Davidson first demonstrates how standard asymptotic theory can be used to derive many of the important properties of partial sums and Brownian motion (B). For example, for $u_t \sim$ i.i.d.$(0,1)$ and fixed $r \in (0,1)$, the weak convergence result $(1/\sqrt{n})\sum_{t=1}^{[nr]} u_t \xrightarrow{d} B(r) \sim N(0,r)$ is a trivial application of the Lindedberg–Levy CLT. The extension of this result to joint convergence over the continuum $0 \leq r \leq 1$ then motivates discussion of the functional CLT. The text next works through the convergence of the autoregressive coefficient to the Dickey–Fuller distribution and further extends these results to allow for serial correlation and trends. This solid theoretical background lays the foundation for a clear development of the augmented Dickey and Fuller (1979) (ADF) and Phillips and Perron (1988) (PP) unit root tests and also the Kwiatkowski, Phillips, Schmidt, and Shin (1992) (KPSS) test for stationarity.

Although the chapter does an excellent job introducing the basic theoretical results, there are arguably some important topics that have been omitted. For example, local to unity asymptotics (see Phillips, 1987) have provided a useful means of analyzing the power of unit root tests. Of particular interest has been the use of this framework to modify the standard ADF and PP tests so as to provide substantial power improvements (see Elliot, Rothenberg, and Stock, 1996; Phillips and Lee, 1996). Two other interesting topics that might also have been worthy of mention are the Bayesian-classical debate over unit root testing (e.g., Sims and Uhlig, 1991; Phillips, 1991) and the observational equivalence between $I(1)$ and $I(0)$ processes (see Hamilton, 1994, Secs. 15.4, 17.6, and references therein).

Chapter 15 provides a comprehensive introduction to single equation cointegrating regression. The chapter begins with the limit behavior for the static OLS estimator applied to cointegrating regression. This is accompanied by an informative comparison of the endogeneity issues in cointegrating and stan-

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dard regression. There is also a good discussion of the bias terms together with a straightforward derivation of the mixed normal distribution that results under strict exogeneity. More appropriate methods of estimating the cointegrating vector, such as the Phillips and Hansen (1990) non-parametric correction, the leads/lag approach (Phillips and Loretan, 1991; Saikkonen, 1991; Stock and Watson, 1993),[1] and the error correction method are then developed. This is followed by analysis of the spurious regression and the Phillips and Ouliaris (1990) residual based cointegration tests. Finally, the chapter tackles the subtle issues involved in modeling deterministic trends together with cointegration relations. Overall, the chapter is both thorough and clearly developed, providing an excellent introduction to this material. One minor point worth mentioning is that although most of the results are derived within the text itself, one of the more important theoretical results, the weak convergence of terms such as $(1/n)\sum_{t=1}^{n} x_t u_t$ for x_t $I(1)$ and u_t $I(0)$, is cited without proof or explanation. The basic heuristic arguments behind this result (see, e.g., Hansen, 1992) are informative but not overly difficult and might have been profitably included.

The final chapter, 16, covers the Johansen or system approach to cointegration. It includes reduced rank regression, the maximal eigenvalue and trace tests for cointegration rank, inference on the cointegrating vector, and extension of the analysis to cover and test for deterministic trends. There is also an interesting section devoted to estimation of structural cointegrating parameters, including reference to some of the author's own work and also to that of Johansen and Juselius. The text discusses conditions under which structural parameters in a cointegrating vector can be identified and estimated by single equation methods. It also shows how to incorporate structural restrictions into the reduced rank regression. Inclusion of this material seems useful because, when using a reduced form system approach, it can sometimes be difficult to provide a clear economic interpretation of the estimated cointegrating vectors. The chapter is thorough and well written, deriving most of the important results within the text. The reader should nonetheless be warned that this is likely the most difficult chapter in terms of the technical material.

3. CONCLUSION

In summary, this book provides a lucid and rigorous development of both econometrics and time series. It should provide an excellent text for either a second or third semester Ph.D. econometrics course or a specialized course on time series. With much thoughtful discussion and coverage of advanced topics, it will also provide interesting reading and a useful reference for econometricians.

NOTE

1. Somewhat confusingly, the leads/lags methodology isn't specifically mentioned by name, although the approach seems to be implicitly discussed in Section 15.2.4.

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