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BOOK REVIEWS

A COURSE IN ECONOMETRICS
Arthur Goldberger
Harvard University Press, 1991

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Arthur Goldberger's new text, *A Course in Econometrics*, is directed toward an audience of first year graduate students. Since virtually every economics department recognizes that an understanding of econometrics is central to graduate training, the demand for such a text is large. I believe that this book is an excellent choice for first year graduate econometrics courses because it provides a solid foundation in statistical reasoning in a manner that is both clear and concise. It addresses a number of issues that are of central importance to developing practitioners and theorists alike and achieves this in a fairly nontechnical manner.

The principal drawback that many prospective buyers may have is that it does not encompass enough topics, and it undoubtedly would need to be supplemented to provide a complete first year course in econometrics. In particular, Goldberger's treatment of systems of simultaneous equations and his chapter on discrete dependent variable models are too narrowly focused. In addition, the book is not completely successful in overcoming the deficiencies of other texts in the area of asymptotic theory. Yet I would still rely on this text for basic econometric principles. While it may not be especially broad, it is quite deep, and the topics addressed here are rarely given such a thorough treatment in econometrics textbooks. For example, in discussions of bivariate distributions Goldberger points out that two uncorrelated normal random variables may not be independent, since a nonnormal bivariate distribution can generate normal marginal distributions. Other texts typically leave readers with the impression that two uncorrelated normal random variables are independent without any reference to their joint distribution.

A comparison of *A Course in Econometrics* with Goldberger's classic 1964 treatment, *Econometric Theory*, reveals that in many ways the new work is a distillation of the old. The background material on statistics is broader with a better motivation for the econometric examples. The conditional expectation function is now treated independently of the linear regression model, providing a logical connection to nonlinear models. Finally, every reader ben-

I would like to thank Julia Lowell and Peter Phillips for numerous helpful comments.

efits from the accumulated insights the author brings to bear in his new chapters concerning collinearity and identification. However, in an effort to present a more unified text, some material from *Econometric Theory* has been omitted. I particularly missed the sections concerning maximum likelihood estimation in simultaneous equations models. I also wish that the very thorough treatment of matrix algebra in the early text, especially the section on differential calculus in matrix notation, had been preserved in an appendix. Thus, although Goldberger's new text does not cover all of the developments in econometrics since the release of his earlier work, it is nevertheless an excellent reference.

1. THE BASIC STRUCTURE

The book is divided into 34 chapters, each of which is kept brief in an effort to distill the relevant concepts. The first seven chapters cover concepts in probability theory that are necessary for econometrics. Chapters 8 through 12 provide the same coverage for classical statistical reasoning (Bayesian methods are not discussed). Estimation of the classical linear regression model is developed in Chapters 13 through 17 and the assumption that the disturbances are normally distributed is added in Chapters 18 and 19. The next three chapters deal with hypothesis testing in the classical regression model with normal disturbances. Chapters 23 through 28 discuss departures from the assumptions of the classical regression model, Chapter 29 is devoted to nonlinear models, and the remaining five chapters focus on systems of regression equations. Computer exercises in Gauss are liberally provided, which should be successful given the popularity of this matrix programming language (although this reviewer did not undertake any of these exercises).

The underlying theme of the book is the conditional expectation function. In the most general format, given a multivariate distribution for (Y, X) where Y is a scalar and $X \in \mathbb{R}^K$, the conditional expectation of Y given $X = x$ is simply expressed as $E[Y|x]$. This is familiar to all economists through the usual textbook association

$$E[Y|x] = x'\beta. \tag{1}$$

Goldberger's approach avoids reliance on equation (1) and emphasizes from the start that the conditional expectation of Y given x may not be linear, immediately causing students to question the specification of their models. In fact, this goes hand-in-hand with the oft-quoted expression that "all models are misspecified." It also leads naturally to discussion of the conditional variance function, a topic of much current interest in empirical work, which many textbooks fail to include.

The linear model of equation (1) then follows as the linear projection of the conditional expectation function. Using least squares to estimate this relation gives the researcher the best linear predictor of $E[Y|x]$. The author

then leads students to ask whether or not this is an interesting feature of the population rather than focusing on biases that arise from the possible misspecification of the regression function.

With this framework for analysis, estimators are introduced using the analogy principle. This principle matches population characteristics with their sample analogs. In its most familiar guise, the analogy principle is simply the method of moments, but it also encompasses probabilities, maxima and minima, and conditional expectation functions. With this broad overview in mind we can now delve deeper into each chapter.

2. A DESCRIPTION BY CHAPTER

The first chapter sets the tone for the book, providing an excellent introduction and describing the tension between the deterministic relations of economic theory and the stochastic relations of empirical work. Students immediately confront questions about the nature of the error term appended to estimable equations and its relation to correct specification of the model. Also, the author's ability to present more advanced concepts in a simple framework is displayed when the law of iterated expectations appears through a simple bivariate frequency calculation.

In the second chapter univariate probability models are introduced. Unfortunately, Goldberger also introduces a large number of acronyms, which then appear frequently throughout the remainder of the book. I found this to be rather distracting, for example one tends to forget that ZES (zero expected score) stands for maximum likelihood. Also in presenting the method for finding the density of $y = g(X)$ I would like to see the more familiar method that begins with

$$F_y(Y) = P(y \leq Y) = P(g(x) \leq Y) = P(x \leq g^{-1}(Y)) = F_x(g^{-1}(Y)).$$

The author's reliance on examples avoids explicit mention of this method and it is quite possible that students could omit the absolute value sign from the Jacobian.

Chapter 3's treatment of univariate expectations is laced with more material that will make students think while exposing them thoroughly to a topic. As an example, readers are reminded that the average value of a Bernoulli random variable is typically a value that never occurs—questioning the casual intuition that the mean is the value that occurs “on average.” Further, the very useful but often omitted Markov inequality is presented alongside the more familiar Chebyshev and Jensen inequalities. The fourth chapter lucidly discusses conditional probability densities for both discrete and continuous random variables. In the fifth chapter, covering expectations for univariate distributions, econometrics and statistics are interlaced in a natural manner. Conditional means are motivated using regression equations and conditional variances are introduced here as well. The law of iterated expecta-

tions is carefully explained and the distinction between the best linear predictor and the best unbiased predictor is emphasized. Once again this encourages students to think carefully about model specification.

Chapters 6 and 7 conclude the probability section of the book with a thorough examination of the concept of independence and normal distribution theory. There is much of use here that is rarely discussed in textbooks such as the distinction between mean independence and independence. Also, as mentioned earlier, it is pointed out that uncorrelatedness only implies independence if the joint distribution of two random variables is normal, since marginal normals can arise from a nonnormal joint distribution.

The eighth chapter introduces statistical estimation. The construction of sample moments to estimate population moments is emphasized and the mean and variance are derived for both the sample mean and the sample variance. The chi-square and Student's- t distributions are introduced and used to derive the distributions for sample moments constructed from a univariate normal population.

The ninth chapter is devoted to asymptotic theory. It is here that Goldberger's nontechnical exposition becomes difficult. Although he conveys a number of the ideas that are important for an understanding of this topic, some key concepts are omitted entirely. For example, there is no distinction drawn between the moments of the limiting distribution and the limits of the moments. I also believe it would have been helpful to include Feller's example distinguishing between weak and strong convergence; while this distinction may not be vital in applications it does help students understand the various concepts of stochastic convergence. The terminology used in this chapter, although it is used occasionally elsewhere, could prove confusing. The term "limiting distribution" is used to describe the behavior of a standardized estimator as the sample size grows arbitrarily large. The term "asymptotic distribution" refers to an estimator associated with a given sample size as the number of samples grows arbitrarily large. Since this last concept is not what one typically thinks of in conjunction with asymptotic arguments, it could mislead readers.

The next chapter employs the asymptotic results in its discussion of bivariate sampling theory. A number of examples are provided to motivate them, leading to the development of the bivariate delta rule. Chapter 11 expands the discussion of estimation using the analogy principle and describes the criteria used to judge an estimator. Using the exact sampling theory already developed for population moments, confidence intervals are introduced. Once again, the solid statistical foundations of the book distinguish it in two ways: first, it is pointed out that no general minimum variance unbiasedness result exists for estimators of the variance, and second, that standard errors rather than t -ratios should be reported with parameter estimates.

The twelfth chapter concludes the section on statistical estimation with a discussion of the information content of a sample and its relation to the

Cramér-Rao lower bound. The likelihood concept is used to derive the score function and the information matrix. This provides a secure foundation on which to introduce the maximum likelihood estimator. However, Goldberger's reliance on the analogy principle to stress an equivalence between maximum likelihood estimation and zero expected score estimation is unfortunate. I believe his approach masks the importance of the maximum likelihood technique.

The thirteenth chapter begins the section on the linear regression model with a thorough algebraic treatment of estimation in the bivariate case, which leads directly to nonlinear model estimation and sample selection bias. Here the differences between maximum likelihood estimation, nonlinear least squares, and instrumental variables estimators are stressed. Again, I feel the importance of maximum likelihood is downplayed. The fourteenth chapter covers algebra for the multiple regression model, with particular emphasis on the non-full-rank case. This material is not central and might have been left to an appendix. The fifteenth chapter further develops the multiple regression model and presents the Gauss-Markov theorem.

Chapter 16 provides a strong presentation of the classical linear regression model. Goldberger points out that multiple regression is appropriately viewed as stratified sampling, not random sampling, and that causal links are not a part of the model. He also describes the two sources of error present in constructing a forecast and covers analysis of variation clearly. (Unlike many texts he offers a lucid explanation of why R^2 may not be contained in $[0,1]$ when an intercept is excluded.) Finally, Goldberger criticizes reliance on R^2 and cautions against the unthinking acceptance of a specific formula for \bar{R}^2 . The seventeenth chapter conducts several familiar exercises to help readers with their interpretation of the linear regression model. He cleverly uses both the two-step residual regression and a model with two sets of independent variables to motivate trend removal, seasonal adjustment, and the bias-variance tradeoff that results when variables are omitted.

The eighteenth chapter covers the basics of quadratic forms for normal random variables and their population moments in linear relations. In the nineteenth chapter the classical linear regression model is expanded to include normality. As elsewhere in Goldberger, more material is covered than is typically found in an econometrics text; for example, there is a thorough coverage of confidence regions for tests involving more than one parameter. The twentieth chapter has a good discussion of size and power, introducing the noncentral chi-squared distribution and showing how power depends on both the magnitude and the *direction* of the departure from the null hypothesis. The next two chapters introduce the case in which σ^2 is unknown, discuss one-sided alternatives, and give readers guidance on the choice of significance level.

Chapter 23 is one of the book's highlights. It is a humorous and pointed treatment of collinearity among the regressors using the concept of micro-

numerosity (small sample size) as a parody. As an example, Goldberger points out that estimating the significance of collinearity is ridiculous; he does this by comparing it with estimating the significance of the sample size. The twenty-fourth chapter presents an overview of model specification, and discusses pretest estimation and the costs involved in specification searches. Chapter 25 expands the classical regression model to include stochastic regressors.

To lay the groundwork for violations of the assumption that the errors have a scalar covariance matrix, Chapter 26 introduces several time series concepts. Basic autoregressive and moving average models are described in conjunction with a discussion of stationarity and its importance for estimation. The next two chapters continue with coverage of heteroscedasticity, autocorrelation, and the method of generalized least squares, but asymptotic theory is not included. Nonlinear models are discussed in Chapter 29; there is a thorough introduction but again no asymptotics.

Seemingly unrelated regressions are introduced in Chapter 30, and Chapter 31 gives an impressive discussion of structural parameters. In the final three chapters systems of simultaneous equations are presented. While the issue of identification is discussed very clearly, the description is not all encompassing: The author chooses to exclude any discussion of rank and order conditions. Estimation coverage is fine for least squares, but full information maximum likelihood is not completely explained and limited information methods are ignored.

3. CONCLUSION

A Course in Econometric Theory is rigorous, it makes students think hard about important issues, and it avoids a cookbook approach. For these reasons I strongly recommend it as a basic text for all first year graduate econometrics courses. Unfortunately, as evidenced by Goldberger's numerous references to other authors, it will not be sufficient as the only text. The derivation of estimators for nonlinear models and important asymptotic results are omitted and the reader is forced to consult other sources. I would recommend Greene's *Econometric Analysis* as a supplement.

In summary, I would use *A Course in Econometrics* in conjunction with *Econometric Analysis* for a first year graduate course in econometrics. Together they provide both the strong statistical foundation and the breadth of coverage required for econometric practitioners and theorists alike.