Causality: Models, Reasoning, and Inference. By Judea Pearl. Cambridge, New York and Melbourne: Cambridge University Press, 2000. Pp. xvi, 384. $39.95. ISBN 0–521–77362–8. *JEL 2000–0834*

This book begins with a very appropriate quote by Albert Einstein, "Development of Western science is based on two great achievements: the invention of the formal logical system (in Euclidian geometry) by the Greek philosophers, and the discovery of the possibility to find out causal relationships by systematic experiment (during the Renaissance)" (p. v). In light of the second part of this quote, the book undertakes the important task of developing a logic based mathematical foundation for the analysis and exploration of causal linkages among variables of interest to practitioners in the physical, behavioral, social, and biological sciences.

The way in which the author undertakes his stated task is quite interesting, and in a way somewhat novel to the literature, as much focus is placed on formally laying out a philosophical and mathematical foundation for understanding causality, although a substantial effort at developing probabilistic and statistical tools with which to carry out inference is also made. Much of this groundwork is based on the use of graph theory and associated probabilistic analysis, and focus is never far from the notions of inferred causation, causal diagrams, and the use of structural models and associated counterfactuals to uncover causal orderings.

His use of graph theory, and in particular the directed acyclic graph (DAG), should not be surprising to the reader familiar with the literature on artificial intelligence; a literature to which the author of this book has made many important contributions. In this literature, as in the book, much focus is placed on providing an axiomatic foundation from which systematic approaches to inferring causal orderings can be derived. The axiomatic foundation is based on notions such as Occam's Razor (i.e., theories that survive well designed selection processes are in some sense minimal) and definitions of causal structure, causal models, inferred causation, minimality, and consistency, for example. All of this is done by the end of chapter 2, culminating in the discussion of the so-called IC (inductive causation) algorithm for uncovering DAGs. This algorithm is based on examining conditional independence relations among variables in a causal structure. In many cases, these conditional independence relations can be viewed as partial correlations, for example, and computer programs can (and have) been written to uncover DAGs based on the use of algorithms such as the IC algorithm.

The book does much more than present algorithms for uncovering causal structures and their related DAGs, however. The book also addresses important and ageless issues of bi-directional causality, structural and reduced form models, latent variable models, identification, and temporal ordering, to name but a few. In summary, chapter 1 introduces basic concepts of probability, graph theory, and causal modeling. Chapter 2, as mentioned above, develops a theory of inferred causation. Chapter 3 continues by outlining many important features of graphical causal analysis such as controlling for spurious inference due to missing variables and using the so-called "calculus of intervention," which allows us systematically to assess the impact of policy intervention, for example.

In chapter 4, the main focus is on identifiability of causal models, while chapter 5 discusses the use of structural models and causality in the social sciences and economics, with some emphasis being placed on the notions of contemporaneous correlation, partial correlation, and the partial regression coefficient. However, discussion does not include the economic concepts of consistent estimation and generated regressors, leaving open the issue of how to test for specific DAG structures when using residuals from estimated regression models, for instance. These sorts of topics are left to the statistical literature on causality, a literature that has flourished in economics, and in particular in econometrics (largely due to the seminal papers of Clive W. J. Granger at the University of California, San

Diego). Chapter 6 continues the important discussion of when causal models can be confounded, and introduces Simpson's Paradox, a paradox which was discussed as far back as 1899 by Karl Pearson, who noted that, "To those who persist in looking upon all correlation as cause and effect, the fact that correlation can be produced between two quite uncorrelated characters A and B, by taking an artificial mixture of the two closely allied races, must come as rather a shock" (p. 176).

Chapter 7 elucidates with great detail the logic of structure based counterfactuals, using policy analysis in a two equation linear econometric model as well as the notions of causal ordering developed by Herbert Simon as vehicles for his discussion. Chapters 8 and 9 continue to detail the implementation of Pearl's refined methodology of causal analysis, with much focus on the use of conditional probabilistic statements and with the help of numerous interesting examples. The last chapter in the book, chapter 10, is an essay that revisits all of the earlier arguments made for formalizing causal analysis and makes numerous interesting arguments about the very definition of causality and what we think of as causality. Finally, the epilogue to the book is the transcript of a public lecture given on "The Art and Science of Cause and Effect." This is a fitting end to a book that sets out to completely formalize our notion of causality and to present us with a mathematical and probabilistic framework that allows for practical implementation of causal analysis—and which to some extent actually succeeds!

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