Econometric Analysis of Stochastic Dominance

This book offers an up-to-date, comprehensive coverage of stochastic dominance and its related concepts in a unified framework. A method for ordering probability distributions, stochastic dominance has grown in importance recently as a way to measure comparisons in welfare economics, inequality studies, health economics, insurance wages, and trade patterns. Whang pays particular attention to inferential methods and applications, citing and summarizing various empirical studies in order to relate the econometric methods with real applications and using computer codes to enable the practical implementation of these methods. Intuitive explanations throughout the book ensure that readers understand the basic technical tools of stochastic dominance.

Yoon-Jae Whang is Professor of Economics at Seoul National University. He is an elected fellow of the Econometric Society and the *Journal of Econometrics* and is Co-Director of the Center for Econometrics at Seoul National University.

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Concepts, Methods, Tools, and Applications

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To my parents
and
Mi Kyung, Sun Young, and Soo Young

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Preface

Stochastic dominance (SD) is an ordering rule of distribution functions. Since the work of Hadar and Russell (1969), Hanoch and Levy (1969), and Rothschild and Stiglitz (1970), the concept has been theoretically explored and empirically implemented in various areas including economics, finance, insurance, medicine, and statistics. The stochastic dominance rule is based on the expected utility paradigm and gives a uniform ordering of prospects that does not depend on specific utility (or social welfare) functions. For example, it can produce a majority assessment (valid over a large class of utility functions) on investment strategies, welfare outcomes (income distributions or poverty levels), and program evaluation exercises. In contrast, the traditional strong orders, based on specific indices of inequality or poverty in welfare, mean-variance analysis in finance, or performance indices in program evaluation, do not achieve consensus. In addition, the stochastic dominance rule does not require restrictive parametric assumptions on the distributions of the prospects.

Since the early work of McFadden (1989), a substantial body of literature has been developed on nonparametric inference on stochastic dominance and its related concepts. The stochastic dominance relation corresponds to an inequality restriction between (functionals of) nonparametric distribution functions. Not only is its statistical inference complicated, but it is also multifarious; since the concept of stochastic dominance itself has many variants in different contexts, it calls for separate inference procedures.

The purpose of this book is to provide an overview of the literature in a unified framework, with a focus on recent developments. There are excellent books on stochastic dominance, including Levy (2016) and Sriboonchita, Wong, Dhompongsa, and Nguyen (2010). There are also several surveys: Levy (1992), Maasoumi (2001), Davidson (2010), and Guo (2013). However, the main focus of the two books mentioned is on the theoretical aspects of stochastic dominance rules in finance, rather than on statistical inference for the rules. Also, the coverage of the surveys is somewhat limited. In contrast, this book

provides up-to-date and comprehensive coverage of the inference methods proposed in the literature. This book also cites and summarizes several empirical studies that employ the inference methods, so that the reader can relate the econometric methods to real applications.

This book is intended for graduate students and researchers in economics and other sciences who are interested in applications of the stochastic dominance rules. It is also useful to theoretical econometricians as a reference, because it shows several examples of using modern econometric tools to compare functional variables and suggests some open questions. It is expected that the reader has a good background in econometrics at the level of, for example, Greene (2012) or Hayashi (2000). Some knowledge of nonparametric inference methods and probability theory would be desirable but is not essential.

I am grateful to many people who helped me in the writing of this book in one way or another. First of all, I would like to thank my advisors, Professors Don Andrews and Peter Phillips at Yale, for their encouragement and support in the early 1990s. My special thanks also go to Oliver Linton, who introduced me to the fascinating topic of stochastic dominance, and who has been working together with me on various subjects over the past decades. I am also grateful to Gordon Anderson and Kyungchul Song, who read an earlier version of the entire manuscript and gave me very useful comments. I also owe a great intellectual debt to Xiaohong Chen, Doo-Bong Han, Yuichi Kitamura, Sokbae Lee, Haim Levy, Essie Maasoumi, Taisuke Otsu, Joon Park, Thierry Post, and Myung Hwan Seo. Parts of this book were written while I was visiting the Cowles Foundation at Yale, whose hospitality is gratefully acknowledged. Deborah Kim (now a graduate student at Northwestern) wrote the MATLAB code in Appendix B, which I deeply appreciate. I also thank Yeongmi Jeong, MinKyung Kim, Sue-Youl Kim, and Jaewon Lee (now a graduate student at Yale) for their excellent research assistance. Thanks also go to Jooyoung Cha, Danbi Chung, Jae Yu Jung, Eunsun Kim, Hyunkyeong Lim, and Siwon Ryu for their careful proofreading. This book was financially supported by the Korea Research Foundation Grant funded by the Korean Government (NRF-2011-342-B00004).

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Abbreviations and Notation

CDF	cumulative distribution function
CDTE	conditional distributional treatment effect
CLT	central limit theorem
EL	empirical likelihood
FSD	first-order stochastic dominance
i.i.d.	independent and identically distributed
LCM	least concave majorant
LFC	least favorable case
PDF	probability density function
QTE	quantile treatment effect
SD	stochastic dominance
SDE	stochastic dominance efficiency
SM	stochastic monotonicity
SMM	studentized maximum modulus
SSD	second-order stochastic dominance
TSD	third-order stochastic dominance
WLLN	weak law of large numbers
$\succeq_s$	stochastic dominance at order s
$F^{(s)}(x)$	integrated CDF at order s
$\bar{F}^{(s)}(x)$	integrated empirical CDF at order s
$D_{1,2}^{(s)}(x)$	difference $F_1^{(s)}(x) - F_2^{(s)}(x)$ between integrated CDFs
$\bar{D}_{1,2}^{(s)}(x)$	difference $\bar{F}_1^{(s)}(x) - \bar{F}_2^{(s)}(x)$ between integrated empirical CDFs
$Q^{(s)}(x)$	integrated quantile function at order s
$[x]_+$	$\max\{x, 0\}$ (i.e., maximum of x and 0)
$[x]_-$	$\min\{x, 0\}$ (i.e., minimum of x and 0)
$a \vee b$	$\max\{a, b\}$ (i.e., maximum of a and b)
$a \wedge b$	$\min\{a, b\}$ (i.e., minimum of a and b)
$sgn(x)$	sign of x
$\to_p$	convergence in probability

$\Rightarrow$	convergence in distribution or weak convergence
$x := y$	equality by definition (i.e., x and y are equal by definition)
$X \overset{d}{=} Y$	equality in distributions (i.e., X and Y have the same distribution)
$A^\intercal$	transpose of matrix A
$f'(x)$	first-derivative of f with respect to x
$f''(x)$	second-derivative of f with respect to x
$\mathbb{Z}$	standard normal random variable, $N(0, 1)$
$U(a, b)$	uniform distribution on (a, b)