

Rejoinder

G. Alastair Young

I am grateful to the Editors for arranging such a perceptive and informative discussion of my article. Discussants range from the designer of the bootstrap, through some of the principal architects of bootstrap methodology, to those at the sharp end of statistical practice who can provide sound judgments on the usefulness of the bootstrap in action, and even to someone who is firmly antibootstrap. I should thank the discussants especially for providing a number of concrete examples, more incisive than those in my article, which both endorse and refute some of the arguments I put forward. The discussion also highlights a number of potential applications of bootstrap which were not described in my article.

There are a number of themes which recur throughout the discussion. I should like to make some brief remarks on these before, in random order, replying to other points raised by each of the discussants in turn.

THINK FIRST, THEN BOOTSTRAP

The bootstrap is no surrogate for careful thought on a statistical problem and, despite the name, it is foolish to think of it as such or to portray it as such. The bootstrap must be applied consciously, not blindly. Applied blindly, the bootstrap often cannot be trusted, and it is always necessary to formulate in precise terms the problem being tackled. Instead, what bootstrap allows is a means, usually via Monte Carlo and the computer, of incorporating the fruits of careful thought into an analysis in a way that is often impossible within the restrictions of standard, off-the-shelf, statistical procedures. It is desirable that implementation of a bootstrap analysis should be automatic, but this should not be confused with the idea that bootstrap should automatically be applied.

COMMUNICATION OF IDEAS

A number of the remarks made by discussants relate to education and communication, and there is strong agreement that something needs to be done here. Among practitioners, there is much dissatisfaction with the processes by which research findings are transmitted to potential users. There is too little exposition of bootstrap in the applications-oriented literature and too much bootstrap research

is driven by abstract thinking, rather than by the particular needs of specific data analyses. There are exceptions, as many of Professor Efron's contributions to the literature demonstrate, but these are too few. As well as researchers on bootstrap methodology becoming more involved in applications, so that the really relevant research questions can be formulated, broadcasting the bootstrap message requires, as Professor Beran points out, a considerable update of statistical education. Also, communication must be a two-way process, with practitioners indicating more loudly what they would like from the bootstrap and researchers advertising their products more keenly.

THE COMPUTATIONAL PLATFORM

Another recurring theme of the discussion relates to the computational platform upon which applied statisticians do their work. Efron suggests that use of bootstrap and other resampling methods will develop rapidly with increased availability and use of interactive computing environments for data analysis such as S-PLUS. The support for this view from Drs. Meredith and Morel suggests that my assessment of the difficulties of packaging the bootstrap paradigm is unnecessarily pessimistic. The trend in applied statistics is toward the use of computing environments within which the bootstrap has a very natural place. In the meantime, like Professor Hinkley, I feel there is an urgent need for better software products specifically designed to implement bootstrap analyses.

DEVELOPMENT OF PROTOCOLS

A theme of much of the discussion relates to the rather bewildering array of potential bootstrap algorithms and of the need for stronger practical guidance of what to use when. My article focussed strongly on the complexities of the more sophisticated variants of bootstrap and suggested that such complexities inhibit adoption of bootstrap ideas by practitioners. The discussion suggests, however, that this may not be the main problem and that the primary need may be to provide practically useful guidelines on use of bootstrap in a number of quite specific settings. Hinkley suggests that simple protocols could be laid down for bootstrapping