entirety. In reading Roberts' essay, I was reminded of the fact that all of the concepts of quality improvement and all of the emphases on interdisciplinary problem solving mentioned by him are applicable to education. Faculties in schools of business are also dealing with processes that can be, and need be, improved based on factual information. Improvements in education, as in business, require teamwork and a point of view that focuses on the problem as a whole.

In my opinion, one of the biggest handicaps to substantial improvements in business education is the current emphasis on disciplines. This emphasis, together with strong disciplinary departments in many business schools, frequently have led to curricula that are made up of compartmentalized courses, with at most one or two capstone courses intended to provide integration.

This fragmented approach to curriculum construction is contrary to the message presented by Roberts that statistical thinking must permeate an organization and that business problems are interdisciplinary problems. While Roberts is writing from the perspective of statistics in business, these ideas extend to curriculum construction for educating future business managers. The interdisciplinary nature of business problems requires an interdisciplinary approach to the construction of the curriculum for business students. Many business problems involve several functional fields, such as marketing and finance, and may require optimization techniques developed by management scientists, statistical analyses for key portions of the problem, and communications experts and management information systems experts for implementation. Thus, it is parochial to believe that statistical thinking can and should be taught solely in a single statistics course, anymore than that the ideas of quality improvement should be taught in a single course on quality improvement or that communications skills should be taught in a single course in communications.

We academicians in business schools claim that we have the tools for businesses to solve their interdisciplinary business problems, but we are reluctant to apply the same tools to our own business, that of education. I agree with Roberts that the current structure of incentives in universities is a major deterrent to quality improvement activities at universities. But that is no reason to give up before an effort has even been made.

The improvements I am thinking about cannot be made by statisticians by themselves, anymore than by accountants or management scientists by themselves. We statisticians need to talk not just among ourselves, but with our colleagues from the other disciplines in business schools. It is my hope that Harry Roberts, together with other statisticians in business schools, will expand their efforts to work with business school faculty members from other disciplines in bringing about the needed changes, so that the business managers of the future will have the outlook and habits of statistical thinking necessary to improve business practice.

Comment

John W. Pratt

My only significant disagreements with Roberts concern Occam's razor and time series. Also I am more pessimistic than he is about the corporate and educational climate for statistics. Otherwise I am in broad agreement with this thoughtful views and remarks, and nothing I say should be interpreted otherwise, though I won't calibrate my reactions on the scale from "Amen" to "Hear! Hear!"

Occam's razor (parsimony) as discussed here, and by other outstanding practical statistical philosophers, cuts too much and too indiscriminately by far, I believe. Consider eliminating "unnecessary" variables in regression. The better the included variables can proxy for them, making them more "unnecessary," the more the included coefficients will be affected and the more the standard errors of these coefficients will be reduced. These are important and unsignaled biases when the coefficients are interpreted as effects. Causal interpretations of nonrandomized data will be completely vitiated if parsimonious dicta are followed. Obvious mistakes of this kind will presumably be avoided in practice, but not subtler ones. Witness the plethora of preliminary tests of significance. Even in passive forecasting, eliminating variables can easily

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mislead. It matters little if it has little effect on forecasts, but if it has much effect, it should be worrisome. It smuggles in sharp constraints without appropriately paying duty classically or setting priors Bayesianly. It may be better in some cases and respects, but its dangers are little understood or discussed at the user (or perhaps any) level. Some aspects of my views are discussed further in Pratt and Schlaifer (1988).

Time series data are indeed common and difficult to interpret, but the theory and methods and computer programs commonly labeled "time series" handle far too narrow and limited a range of problems to demand extended attention by general managers or in general business education. With little more than lagged dependent variables, little but routine passive forecasting can be done, and that is best left to specialists. Interpreting ARIMA models is exceedingly tricky; models that look very different may be very similar (in pure autoregressive form, say), and smuggling in constraints is the name of the game. I'm not saying simple trend and seasonal analysis solves the problems either, but at least they are less likely to be thought to do so. Regression with uninhibited independent variables and ample, perhaps "distributed," lags, all handled naturally, may be better in practice and in the classroom, at least until we are ready to combine full-blown regression models with ARIMA disturbances.

Having worked for 30 years at a business school that considers itself and probably is the leading supplier of American top management, I have to say that it looks very unlikely to me that statistics is going to flourish naturally in most corporate climates or to be stimulated to do so by top-down fertilization or fiat. Harvard Business School has not been teaching general managers any significant statistics as Roberts or the profession or yours truly thinks of it. If it changed now at the MBA level, the effect would have a mean lag of 15 years or so, and no such change is in prospect. Still less can be hoped for in the executive education (middle and advanced management) programs.

Even if Deming, Juran, Ishikawa, Joiner and others can sell some top managements on statistical needs, and democratize, lengthen the vision of, and otherwise improve corporate culture, the vast body of middle managers whose minds don't work statistically won't change their spots now. I have no solution, but I don't think we should expect either the new philosophies of quality or foreign competition to raise the level of statistics or statistical thinking far or widely or soon.

Some other points:

1. Maintaining clean data bases takes dough as well as discipline. Since neither will often be available, we need methods for dirty data too.
2. Methods of choosing, combining and adjusting estimates based on heterogeneous sources including quickly collected data have been of special interest to Rex Brown (Brown and Lindley, 1986).
3. Since the mid-century (1953) edition of Cochran (1977), my admittedly small efforts have found distressingly little in the development of survey sampling methodology that is easy to understand or compute. Guidance would be greatly appreciated.
4. The leading Japanese universities are not teaching any more statistics than the leading American ones, and their students, faculty, and courses are more theoretical than ours in most subjects, including statistics; at least, so I understand from what Japanese professors have told me. Thus educational differences do not straightforwardly explain the differences in business practice.
5. Not only is it not helpful to discourage interpreting confidence as degree of belief, it is irresponsible, even for unbelieving statisticians, to present confidence intervals that are not so interpretable, at least roughly.
6. Combining statistical forecasts with judgment seems important and tricky and surprisingly little discussed. How do you avoid double-counting information used in different ways by statistics and judgment? Maybe those who know are profiting by not telling.
7. *Ex post* "explanations" of the last data point may be suspect in one sense but not another: valid in terms of the variables invoked, but useless because these variables are neither predictable nor controllable.
8. A lot of statistical design is surprisingly easier than analysis, even since computers, and even though design depends in principle on analysis. Cox (1958) is much easier than any serious analysis book, however applied. Or compare Fisher's design and analysis books (1935, 1954). So the great ideas, including randomization, could be taught in very basic courses. Not to mention issues that are even easier in the sense of less technical, such as what are we trying to measure, how can we measure it, would knowing it really affect managerial decisions? Design problems are also easier in that optima are very flat and commonsense considerations very influential.
9. Economic theory can provide helpful insights even when it is hard to confront it with data, well or badly. I think of competitive equilibrium, economic efficiency, elasticity, comparative advantage, externalities, incentives and so on.

Their usefulness much precedes and exceeds their measurability.

10. Reformulation in terms of Bayesian odds ratios will not rescue standard tail-area testing procedures, I believe. Such odds ratios for lower-dimensional hypotheses are problematic and prior-dependent. And whatever the relation between Bayesian odds ratios and real modeling issues, standard tail-area procedures will have to be transformed beyond recognition to become well articulated to either.

In usual F tests, 1/F has a pleasant interpretation as a shrinkage factor, at least in the balanced case, but this doesn't rescue P recognizably or interpret R-squared directly. (This interpretation is well known, I understand. I noticed it while reviewing Mosteller and Wallace (1964) for the Mosteller Festschrift, when working through the simple normal-theory counterpart of the difficult nonnormal shrinkage and discrimination problem that they solve.)

Rejoinder

Harry V. Roberts

I keenly appreciate the contribution of all the discussants. I have very few disagreements to record, and I have been stimulated to offer some extensions of the paper.

Dr. Deming says that the business of statisticians is to transform the company goals, not to help the management to pursue theirs. Thanks in large measure to his efforts, some companies have already transformed their goals, or are at least far along in the transformation. In these companies, statisticians need to ply their trade skillfully in pursuit of company goals, and to train parastatisticians.

Unfortunately, many other companies have not heard about, understood, or believed, the need for transformation. What do statisticians do when the organizational climate is bad, when management's goals are misdirected? (Dr. Deming once wrote me that the statistician may only prolong the life of a sick company.)

Some of my students, discouraged by the contrast between what goes on in their own companies and the advice of the Deming 14 Points, ask the same question. My first impulse is to say that it a rare statistician in the middle levels of such a company who can do much to transform the organization's goals. But that is not a good enough answer. Since statisticians often have considerable freedom in defining the data and studies on which they work, they can help to educate management. They are free to suggest, for example, that it might be valuable to study quality, lead time and inventories instead of, or at least in addition to, machine utilization, cost variances and quota fulfillments.

George Box expresses my basic view of statistics in one golden sentence and one splendid metaphor. The sentence: "In my view, statistics has no reason for existence except as the catalyst for investigation and discovery." The metaphor: teaching swimming by theoretical training alone, and the tendency of many statistics teachers to avoid getting wet.

Professor Moore's description of the U.K. situation bears many similarities with that of the United States. For example, what he says about the London Business School could be applied with only minor modification to the business school at which I teach; better use of basic statistics to improve quality and productivity is needed in the United States as well as in the U.K. and Europe; and upward mobility of accountants and lawyers is conspicuous in the United States (where Dr. Deming deplores "creative accounting" and calls litigiousness a "deadly disease").

My purpose in citing management books by Peters and others was not to endorse them in all details but to point out that statistics is but one component of a major management upheaval in many world class companies. By the regression phenomenon alone, it is to be expected that studies confined to successful companies at any one time will be embarrassed by problems encountered later by some of these companies. There's more to it than regression, however. Excellence in quality and productivity is no insurance against major management blunders in other areas, such as unfortunate acquisitions.

The mention of writers on management gives me the opportunity to cite a new book by Richard Schonberger (Schonberger, 1990) that carries the story beyond what I reported in my subsection "Beyond Parastatisticians" at the end of Section 3. The new book, *Building a Chain of Customers*, extends the focus from manufacturing to the entire business firm.

I do believe that work of Raiffa and Schlaifer (and, of course, that of Savage and de Finetti) is seminal.