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Communications to the Editor—The Use of Regression Equations to Predict Manpower Requirements: Critical Comments

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COMMUNICATIONS TO THE EDITOR

THE USE OF REGRESSION EQUATIONS TO PREDICT MANPOWER REQUIREMENTS: CRITICAL COMMENTS

In a recent article in *Management Science*,[1] an application of multiple regression analysis to the prediction of departmental manpower requirements was described. Little information was given regarding the data of the study, and little attention was paid to the assumptions of the regression model. This calls into question the conclusions of the study, since the regression methodology contains a potentially serious bias. In view of the economic importance of the problem, the purpose of the present comment is to suggest improvements in the analysis.

I. Summary of the Article

For individual departments in a company, linear multiple regressions were developed of departmental manpower, using quarterly time series of activity data as explanatory variables. The article gives the Finance Department as an example:

$$TM = B_1 + B_2\,(\text{Tot. Co. Emp.}) + B_3\,(\text{Tot. Direct Emp.}) + B_4\,(\text{Co. Sales}) + B_5\,(\text{Rec. Reports Processed})$$

where TM is the department's manpower. The R^2 was 0.8628. The R^2 for other departments' manpower ranged from 0.87 to 0.983.

From the regressions, based on six years' data, departmental manpower was predicted for the next two years. These predictions were then inflated by subjective "complexity factors" to allow for increasing complexity in operations. The inflated prediction estimates were deducted from the respective departments' actual manpower at that time, to arrive at the recommended reduction in manpower for each department. The recommended reductions totaled 3,606 of the company's 29,822 employees.

II. Statistical Methodology

In dealing with time series autocorrelation of the regression residuals is notoriously common. Autocorrelation violates the assumption of zero covariance between any two true error terms[2] in the least-squares linear regression model. If autocorrelation is present and the prediction is based upon simple least-squares, the prediction will be both biased and inefficient.[3] The prediction will be biased, since no account will have been taken of recent estimates of the regression error.[4] The inefficiency results from the fact that generalized least-squares esti-

[1] Albert B. Drui, "The Use of Regression Equations to Predict Manpower Requirements," *Management Science*, Vol. 8, No. 4 (July 1963), pp. 669–677.

[2] Assumption (4–4b) of [1], p. 107.

[3] See [1], pp. 196–197.

[4] The estimates of the regression coefficients would still be unbiased, but the prediction of the dependent variable will be biased.

mators could be developed which are more efficient than the simple least-squares estimators, given that autocorrelation is present.[5]

The author's discussion of *complexity* is highly suggestive of positive autocorrelation. He states that "the only extraneous factors occurring during the past two years that might affect manpower levels were determined to be increased complexity of departmental operations and empire building!"[6] Since an index of complexity was not included as a regression variable, it was implicitly relegated to the residual term, where its increase over time may well have led to significant autocorrelation. Whether or not due to complexity, autocorrelation has the potential to bias the prediction, which necessitates a test for its presence.

An appropriate test to make is the Durbin-Watson d statistic:

$$d = \sum_{i=2}^{n} (Z_i - Z_{i-1})^2 / \sum_{i=1}^{n} Z_i^2$$

where the $Z_i (i = 1 \cdots n)$ are the residuals from a fitted-least-squares regression.[7]

In the only departmental example reported (Finance), the bias due to positive autocorrelation would tend to cause the regression forecast of Finance Department manpower requirements to lie below the "true" relation. Evidence of this can be seen in Figure 2, p. 674 of the article. For the last three quarters of the base period, the fitted regression equation has underestimated the actual requirements. If positive autocorrelation exists, as it likely does with complexity increasing over time in the residual term, then this tendency of the fitted regression equation to underestimate the true relationship will continue into the prediction period. Hence, the recommended manpower is biased toward reduction exceeding that which the "true" relationship would require.

The arbitrary adjustment of regression predictions by means of subjective "complexity factors" seems illogical. If, in fact, complexity was increasing over time, an independent complexity variable could have been included in the regression. If, on the other hand, there was a discrete quantum "explosion" of complexity, such a structural change would invalidate further use of the regression model anyway.[8]

III. Evaluation versus Prediction

The author recommends that present manpower should be reduced to the level of his adjusted estimates. But predictions of future manpower requirements depend, of course, on the predicted future values of the independent variables. The author's recommended policy of manpower reduction implicitly assumes

[5] See [1], Chapter 7.

[6] *Op. cit.*, p. 675.

[7] [1], p. 192. If the d statistic detects the presence of autocorrelation, then an alternative estimation procedure would be the iterative procedure outlined in [1], pp. 193–194. One caution is in order. In a forthcoming comment in *Econometrica*, Nerlove and Wallis show that d is asymptotically biased toward showing no autocorrelation when lagged endogenous variables are present. Hence, if a revised version of the equations had TM lagged as an independent variable, the d statistic would be biased.

[8] A technique for the case of a discrete structural change (providing that the change can be specified) is given in [2]. If the discrete change point is within the time interval used for estimation, a dummy variable approach might be appropriate. See [1], Chapter 8.

that there will be no change in the explanatory variables between the eighth year and the planning time horizon. In view of the evidence from Figure 1 and Figure 2 in the article and the close fits of the regressions, it would appear that past fluctuations render this assumption untenable. Hence, the author's estimates indicate only what should have *been done* in the eighth year—not necessarily what should *be done* for the future. While not applicable to planning in its present form, his procedure, if account is taken of any autocorrelation, may be of use for a *post hoc* evaluation of the efficiency of manpower management in the period just ended. But it is not a useful planning model. The use of lagged, as opposed to current, independent variables could be used to adjust the model to planning purposes.

IV. Manpower Costs

There are some questions of dynamic economic adjustment in the firm. For instance, the efficient contraction curve for a department might well not coincide with its efficient expansion curve, as is implicit in the author's procedure.

Another question is the author's statement that "... it is important that manpower, usually the largest element of cost, be kept at a minimum (p. 669)." He emphasizes the costs of excess manpower and the related deleterious effect on the contract bidding position of the firm. But it is not at all clear that minimum manpower is in any sense necessarily optimum manpower.

This neglects the costs of manpower fluctuations, which can cause considerable recruiting, hiring, training, and termination expenses. A firm with unstable employment practices often must pay premium wages, particularly to skilled technical personnel. It should be recognized that these costs will also be priced into the firm's bidding. Furthermore, there is the variance around the regression estimate to consider. It is not sufficient to use only the point estimate of the mean for decision-making, especially in a situation like this, where costs of manpower shortage and surplus cannot be expected to be symmetrical.[9] There is an obvious analogy here to inventory theory, which has developed useful techniques for just such problems.

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3. Hadley, G. and Whitin, T. M., *Analysis of Inventory Systems*, Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963.

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[9] See, for instance, [3], Chapter 6.