PRODUCTIVITY AMONG SCIENTISTS: A REPLICATION AND ELABORATION* (COMMENT ON ALLISON AND STEWART, ASR AUGUST, 1974)

In a recent article, Allison and Stewart (1974) try to determine whether accumulative advantage—also called "Matthew effect"—has an important role as a determinant of productivity among scientists. Productivity was assessed by obtaining citation counts and self-reports on number of publications for a sample of 1,947 biologists, mathematicians, chemists and physicists. Using a mathematical formulation developed by Simon (1957), Spilerman (1970) and others, Allison and Stewart (1974:598) arrive at the premise that, if accumulative advantage does exist, "the variances of productivity, esteem, and resources will all increase over time...." The highly skewed character of the two measures of productivity necessitates the use of the Gini index as a measure of variability, and when this index is correlated with number of years since receiving the Ph.D. for eight cohorts of scientists (data are aggregated and N=8), the results tend to support the hypothesis of increased variability in productivity with increasing age. It should be noted in passing that since Allison and Stewart have cross-sectional data it is impossible to vary age without varying cohort membership, and vice versa, so that the effects of these two variables cannot be assessed independently.

Allison and Stewart state early in their article that the accumulative advantage hypothesis envisions the possibility of a reciprocal causal process in which productivity at time t might be influenced by access to resources at time t and by "esteem" at time t-1; access to resources at time t-1 might be influenced by esteem at time t-1; esteem at time t-1 by productivity at time t-2, etc. If such a process operates, then at any point in time we would expect productivity to be associated with access to resources, and the covariance of these two variables presumably would increase as a cohort ages; Allison and Stewart find just such associations. Using path analysis, they find also that variability in access to research resources has a substantial impact on the Gini index for productivity, and this result is adduced as further support for the accumulative advantage hypothesis. Again in passing, it should be noted that the equations defining a possible reciprocal causation process seem to be applicable to individual scientists, whereas the analysis conducted throughout most of the article applies to age strata, and this anomaly would seem to create a danger of the ecological fallacy. The authors reveal an appropriate skepticism regarding their own tentative conclusions when they say that the "evidence in support of the accumulative advantage hypothesis does not disconfirm the heterogeneity hypothesis" (Allison and Stewart, 1974:605). The same difficulty was encountered by Spilerman using a similar approach to the study of urban riots, and his preference for the heterogeneity hypothesis was based on extraneous considerations (Spilerman, 1970:637) having nothing to do with the increased variance argument and made possible only by the fact that he had longitudinal data.

Using data from the 1973 American Council on Education survey of American college and university faculty members, 1 the 1972-73 faculty data were collected by the American Council on Education's former Office of Research under a grant from the RANN Division of the National Science Foundation. Data access was achieved through the Council's Division of Educational Statistics, Washington, D.C. I wish to thank the Computer Center of the College of William and Mary for the use of data processing facilities.

*The 1972-73 faculty data were collected by the American Council on Education's former Office of Research under a grant from the RANN Division of the National Science Foundation. Data access was achieved through the Council's Division of Educational Statistics, Washington, D.C. I wish to thank the Computer Center of the College of William and Mary for the use of data processing facilities.

1The ACE survey involved random sampling of faculty members within a disproportionately stratified cluster sample, where each cluster consisted of an individual institution. The final sample size was N=53029. The answers of each respondent must be weighted according to the sampling ratio used for his particular type of institution. Statistical data for any table can be taken as representative of the entire
correlated career age with the variance in recent scholarly productivity for a large sample of faculty members in the social sciences, humanities, biological sciences and physical sciences. As shown in Table 1, the correlations for the four groupings were −.31, .60, .78, and .45, respectively. These results are generally supportive of Allison and Stewart’s conclusions, although I am at a loss to explain the negative correlation for social scientists and the positive correlation for humanities professors, the only group of non-scientists in the sample. On the assumption that accumulative advantage would be more pronounced among research-oriented scholars, separate correlations were obtained for professors at "research universities" or "doctoral-granting universities,"² and the results were somewhat more commensurable with those of Allison and Stewart (Table 2): .47 for social scientists; .42 for humanities professors; .02 for biologists and .68 for physical scientists. Allison and Stewart found also that biologists did not entirely conform to the increased variance model.

It is easy to concur with Allison and Stewart’s contention that merely presenting evidence of increasing variability in productivity with career age does not clinch the argument on accumulative advantage. At best, it can be said that neither the Allison-Stewart study nor the present study has succeeded in eliminating the accumulative advantage hypothesis. In fact, I have strong misgivings about the assumption that an accumulative advantage process would necessarily bring about

*Questionnaire item: How many of your professional writings have been published or accepted for publication in the last two years? None = 1; 1-2 = 2; 3-4 = 3; 5-10 = 4; more than 10 = 5.

**Questionnaire item: Year of highest degree now held
1971 through 1975 = 1; 1968 through 1970 = 2;
1964 through 1967 = 3; 1960 through 1963 = 4;
1955 through 1959 = 5; 1950 through 1954 = 6;
1940 through 1949 = 7; 1939 or earlier = 8.

(Categories based on original ACE questionnaire.)
increased variability in productivity. Spilerman's model, based on a negative binomial distribution, assumes that the occurrence of a race riot necessarily would have to increase the probability of a subsequent riot for us to conclude that a reinforcement process has taken place (Spilerman, 1970:636). If δ represents "disorder proneness" at time t, then δ + μ represents the probability of a riot at time t + 1 (following the occurrence of a first riot) and the probability of, say, a tenth riot is δ + μ. Such a process would place many cities on an upward incline in the number of riots experienced over successive time intervals, and the variability in number of riots among cities would necessarily increase. However, a positive reinforcement process could operate within given cities from time t to t + 1 without producing a greater probability of a riot at time t + 1 than at time t. Similarly, accumulative advantage could influence scientific productivity without producing an increasingly greater probability of publication with each succeeding publication or for each succeeding time interval. The point can be made by means of a least squares approach incorporating "reciprocal causation" equations similar to those introduced by Allison and Stewart (1974:598). To simplify matters without sacrificing plausibility, we shall assume that productivity at time t influences esteem at time t, and that esteem at time t influences access to resources at time t and that access to resources, with some delay, eventually brings about an increase in productivity. We then have the following equations, with $X_1 = \text{productivity}$, $X_2 = \text{esteem}$ and $X_3 = \text{access to research resources}$, in standard form:

$$X_{1t} = \beta_{13} X_3, t-1 + U_{1t}; \quad (1)$$

$$X_{2t} = \beta_{21} X_{1t} + U_{2t}; \quad (2)$$

$$X_{3t} = \beta_{32} X_{2t} + U_{3t}. \quad (3)$$

Substituting equation (2) for the $X_{2t}$ term of equation (3), we obtain

$$X_{3,t-1} = \beta_{32} \left[ \beta_{21} X_{1,t-1} + U_{2,t-1} \right] + U_{3,t-1}. \quad (4)$$

Substituting equation (4) for the $X_{3,t-1}$ term of equation (1), we obtain

$$X_{1t} = \beta_{13} \beta_{32} \beta_{21} X_{1,t-1} + \beta_{13} \beta_{32} U_{2,t-1} + \beta_{13} U_{3,t-1} + U_{1t} \quad (5)$$

### Table 2. Publication* Inequality by Length of Time Since Ph.D.** and Field, U.S. Faculty Members Affiliated with Research Universities and Doctoral-Granting Universities, 1973

<table>
<thead>
<tr>
<th>Length of Time Since Ph.D.</th>
<th>Social Sciences</th>
<th>Humanities</th>
<th>Biological Sciences</th>
<th>Physical Sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.379</td>
<td>1.081</td>
<td>1.093</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>1.226</td>
<td>1.273</td>
<td>1.627</td>
<td>1.676</td>
</tr>
<tr>
<td>3</td>
<td>1.207</td>
<td>1.011</td>
<td>1.636</td>
<td>1.265</td>
</tr>
<tr>
<td>4</td>
<td>.826</td>
<td>1.621</td>
<td>1.008</td>
<td>1.355</td>
</tr>
<tr>
<td>5</td>
<td>1.054</td>
<td>1.307</td>
<td>1.959</td>
<td>1.845</td>
</tr>
<tr>
<td>6</td>
<td>1.590</td>
<td>2.024</td>
<td>1.338</td>
<td>1.349</td>
</tr>
<tr>
<td>7</td>
<td>1.355</td>
<td>.958</td>
<td>1.725</td>
<td>1.929</td>
</tr>
<tr>
<td>8</td>
<td>.937</td>
<td>1.685</td>
<td>1.047</td>
<td>2.714</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regression of Variance on Time Since Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>b: 0.063</td>
</tr>
<tr>
<td>a: .761</td>
</tr>
<tr>
<td>r: .466</td>
</tr>
<tr>
<td>(Weighted) N = 5309, 5182, 2615, 2316</td>
</tr>
</tbody>
</table>

*See note to Table 1.  **See note to Table 1.
or, in non-standard form,

\[ X_{1,t} = A_1 + b_{13}b_{32}b_{21}X_{1,t-1} + b_{13}b_{32}U_{2,t-1} + b_{13}U_{3,t-1} + U_{1,t}. \tag{6} \]

In other words, productivity at time \( t \) is a function of itself at time \( t-1 \) and a series of error terms. If we take the risky step of ignoring the error terms, it turns out that the probability of increased productivity at time \( t \) is a function of the degree to which the product \( b_{13}b_{32}b_{21} \) exceeds unity. For an aggregate of scientists, if the variability in productivity at time \( t \) is \( \sigma \), then the variability in productivity at time \( t_n \) is \( \sigma (b_{13}b_{32}b_{21})^n \), where \( n \) is the number of time intervals through which the reciprocal causation process is allowed to operate, i.e., the number of "cycles" it is allowed to pass through. If \( \sigma^2 \) at time \( t_0 \) is to be greater than \( \sigma^2 \) at time \( t \), then at least one of the regression weights defining the reciprocal causation process must be greater than 1.0. Again in passing, it should be pointed out that ignoring the error terms in equation (6) is a dangerous procedure, particularly since it must be assumed that the error terms for \( X_{1,t} \) are independent of those for \( X_{1,t-1} \). For independent variables of the sort usually invoked under the heterogeneity hypothesis—e.g., "native ability"—this assumption is glaringly unrealistic. In a sense, then, the least squares procedure shows the importance of gaining statistical control over the variety of independent variables which could be introduced under the "heterogeneity" rubric.

Arguments developed by Allison and Stewart, as well as by the present author, have a syllogistic structure that should be described explicitly as a means of clarifying the exact sense in which these arguments are fallacious\(^3\) and therefore not highly compelling:

1. If Matthew effect obtains, then, by definition, there is a positive feedback process linking scholarly productivity at time \( t \) with productivity at time \( t+1 \), with at least one intervening variable involving "reputation."

2. If such a positive feedback process exists, then, by definition, there is at least one independent causal linkage represented, e.g., by \( b_{13}b_{32}b_{21} \), such that the algebraic product of this linkage is greater than zero.

3. If the product \( b_{13}b_{32}b_{21} \) is greater than zero, then this product has a greater than chance probability of being greater than 1.0.

4. If the product \( b_{13}b_{32}b_{21} \) is greater than 1.0, then the variance in scholarly productivity will increase as a cohort moves through its career.

Having established such an increase in variance, having committed the fallacy of asserting the consequent and having retained the qualification in the third premise, we conclude that there is a better than chance probability that Matthew effect obtains. The second premise, which is definitional, is of substantial importance in that the establishment of a positive feedback process requires that a linkage such as \( b_{13}b_{32}b_{21} \) exist independently of a number of extraneous factors, and neither Allison and Stewart nor I have demonstrated such a linkage.

An ingenious study by Stephen Cole (1970) attempts to show a causal nexus between a scientist's "professional standing" and the probability that his published papers will receive early recognition (through citation) independently of the "quality" of such papers as assessed by their long-term citation rates. It was found that recognition accorded papers of equal quality is influenced favorably by a scholar's reputation from past work and by his current institutional affiliation; conversely, a number of other measures of "eminence" were unrelated to citation rates. Cole's study is a prototype of the sort of inquiry essential to an accurate determination of the degree to which Matthew effect exists within the stratification system of science. It is a study of limited scope, merely showing that reputation influences one form of deference independently of "quality." Concepts such as "productivity," "esteem" and "access to resources" subsume a wide variety of phenomena amenable to study using both non-experimental and experimental techniques. Indicators of "esteem," including one's name (or one's sex or ethnicity insofar as these traits are reflected in one's name), one's graduate department, one's institutional affiliation or one's honorific recognition, could be assessed either non-experimentally or (in a few instances) experimentally in relation to indicators of access to resources such as time (or space) available for scholarly endeavors, academic appointments, receipt of grants, availability of research assistants, and so forth. An interesting variation on Cole's methodology, for instance, would consist in comparing publications of equal quality (as assessed, for instance, by long-term citation rates) to determine whether the scholarly repute of their authors had an impact on the likelihood of their acceptance for publication.

---

\(^3\) Blalock (1972:112) argues that the fallacy of asserting the consequent is an inherent element of the research enterprise.
by journals in fields where acceptance rates are relatively low and where there may be significant departures from anonymity in the review process. A similar variation was once attempted by Crane (1967), who, using time-series data, found a consistent pattern of concomitance between the prestige of editors and that of authors for a number of academic journals. Crane, however, used no controls for “quality,” and therefore her study is limited to the method of agreement.

A feedback nexus such as that represented by the expression $\beta_1 \beta_2 \beta_3$ involves lag and implies a certain pattern of change in variables over time; time-series data, then, become appropriate, and in the present instance synthetic cohorts have been used in the hope of replicating such data. Variables involved in positive feedback are mutually reinforcing, and the scalar values of such variables increase indefinitely over time until, eventually, an upper limit is reached beyond which an essentially explosive process is not permitted to continue. Even the most powerful instances of Matthew effect cannot extend beyond the lifetime of a single scholar unless one entertains the possibility of “intergenerational” transmission of scholarly eminence which, according to Zuckerman (1967), seems to exist among Nobel prize recipients “sponsored” by earlier Nobel recipients. In any case, we are not confined to the analysis of individuals as the unit of observation, and future studies of Matthew effect should examine the possibility that organizations such as universities and research institutes may receive rewards based less on performance than on repute. A unique feature of such organizations, of course, is that they are not subject to an inevitable mortality, and therefore Matthew effect, over time, could generate an extremely intense concentration of rewards.

Michael A. Faia  
College of William and Mary  
and  
Centro Intercultural de Baja California

REFERENCES

Allison, Paul D. and John A. Stewart  

Blacker, Hubert M.  

Cole, Stephen  

Crane, Diana  

Simon, Herbert A.  

Spilerman, Seymour  

Zuckerman, Harriet  

REPLY TO FAIA

Faia has presented evidence tending to corroborate our conclusion that productivity becomes distributed more unequally as scientists grow older. Nevertheless, he argues that our formulation of the accumulative advantage hypothesis does not really imply this increasing inequality. In other words, we seem to have gotten good predictions from a bad deductive theory. Specifically, Faia shows that a system of simultaneous equations relating productivity, resources and esteem does not imply an increasing variance in productivity with time unless the product of certain coefficients in the system is greater than one. Since our theory does not specify the values of these coefficients, the deduction breaks down.

Faia is quite correct about the necessary constraints on the coefficients in his simultaneous equation system, but he has neglected to consider some aspects of our line of reasoning. In particular, he has imputed a much greater degree of model specification than we had intended. Before presenting the simultaneous equation system, we briefly discussed several stochastic models which might plausibly be taken to represent the accumulative advantage or reinforcement hypothesis. We added, however, that “an indefinite number of such models could be constructed, and those simple enough to be tractable usually require unrealistic assumptions.” Without opting for any particular model, we noted that models involving positive reinforcement generally imply increasing dispersion with time.

Our prediction that the dispersion in productivity ought to increase with age was based, then, on a survey of several different