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EXPLORATION OF A BIOLOGICAL MODEL OF INDUSTRIAL ORGANIZATION

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Social science research in recent years has been characterized by a search for models and systems to describe significant phenomena. With large-scale industrial organizations increasing in size as well as in significance in our social and economic life, it becomes important to understand better the regularities and forces determining organizational size. With increasing concern for problems of change, growth, and development, investigators have turned to biology, the science most concerned with development, as a source of appropriate models.

This paper describes and tests a model which is found to have significant value for portraying the organizational structure of firms of varying size in several industries. The study also finds a definite relation between proportion of staff engaged in research and general organizational structure of the firm.

A biological model has been proposed by Mason Haire as a means of understanding the growth and form of organizations.[1] Haire proposes the square-cube law as a description of organizational growth and composition. He states:

> The square-cube law says that mass grows by a cube function while surface grows by a square. If one were to take the cube root of volume and the square root of area and plot them for different stages of growth, the result would be a straight line from the origin with a slope of 1. As the cube of the mass doubles, the square of the surface doubles. The line would be described by the single regression formula: $y = a + bx$ in which the intercept is o and b is unity.[2]

Haire measures "surface" and "volume" of the industrial organization by the number of people who inhabit these two areas. "Volume" in this sense refers to employees dealing with the firm's internal functions (e.g., accountants), while "surface" refers to employees dealing with the firm's external environments (e.g., sales). Haire studied longitudinal data on four firms and discovered that the data plots of the cube root of the volume and the square root of the surface indicated remarkably high linear relationships (r's of .95 to .99). All the intercepts were greater than zero on the axis

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[1] Mason Haire, "Biological Models and Empirical Histories of the Growth of Organizations," in *Modern Organization Theory*, ed. Mason Haire (New York, 1959), p. 284.

[2] *Ibid.* Professor Gordon Antelman has observed that Haire's statement, "As the cube of the mass doubles, the square of the surface doubles," is incorrect. It should state that "as the cube root of the mass doubles, the square root of the surface doubles."

represented by the cube root of the mass. The slopes were all positive, ranging from .50 to .97, but fell short of the unity predicted by the square-cube law.

Haire concludes that the square-cube law provides a reasonably good fit of organizational composition while recognizing the deviations from the model in terms of both slope and intercept. We suggest that Haire's *extension* of the square-cube law does give insight into some of the correlations of organizational growth, and, accordingly, we are concerned in this study with exploring further the applicability of the model.

Three general questions are posed in this study. (1) Does the square-cube model apply for a cross-sectional analysis of firms within specific industries? (2) Further extending Haire's model, are there differences among industries in the volume$^{1/3}$–surface$^{1/2}$ regression relationship (i.e., the slope)? (3) Are there plausible reasons for any such variances among industries in relation to environmental accommodation? Affirmative answers to these three questions would further substantiate Haire's model and extend its applicability.

The linearity of the volume$^{1/3}$–surface$^{1/2}$ relationship in the longitudinal study of a given firm may mean that the environment for that firm remains relatively constant in terms of the organizational pattern that must be maintained or extended to be successful in that environment. If this is the case, then a cross-sectional study of firms belonging to reasonably homogeneous industry groupings which share a common environment should similarly display a linear relationship between the cube root of volume (inside employees) and the square root of surface (outside employees). By "environment" we mean the world in which a firm works in relation to the task the firm sets out to accomplish—the state of technology, the nature of the market and marketing modes, the degree of competition, requirements for product or process innovations, if any, expansion or contraction of the market, etc. As this environment differs among industries, one might properly expect that industrial organizations would reflect these differences by specific organizational manpower accommodations.

Data were obtained on sixty-two firms in nine industry groupings. The industries studied were aircraft, chemicals, drugs, food, electronics, electric machinery, machinery except electrical, and fabricated metal products. The firms ranged in size from 272 to 81,227 employees. The number of firms within each industry grouping ranged from five to ten. These data were compiled by the "Group 10 Research Project," a co-operative research group under American Management Association auspices. The data used in the present study represent manpower distributions of these firms during 1960. A number of major industries are not included because an insufficient sample was represented in the Group 10 Project.

Each occupational category or function was assigned to either the "inside" (volume) or "outside" (surface) of the firm. For example, marketing, procurement, and receptionist employees deal with the external environment and were catalogued as outside employees. Conversely, personnel, research, and production functions are inside.

The determination of inside and outside functions departs in some measure from strict adherence to biology. While it is recognized that the digestive system is biologically "outside," the application as a model for industrial organizations becomes unclear. In this sense, the model must be suggestive rather than a precise paradigm. We have chosen to determine inside or outside functions by simply considering whether the function dealt primarily with the external or internal environment of the firm. Manpower were allocated to forty-six separate functions which, in turn, were catalogued as either inside (I) or outside (O). Functions containing both inside and outside personnel were allocated in favor of the preponderance of either inside or outside staffing in the function. The functions and allocations are as follows:

Manufacturing or processing/extracting or producing:
1. Production workers I
2. Maintenance workers I
3. First-line supervision I
4. Auxiliary service
   a) Utilities and waste disposal . . I
   b) In-plant transportation and materials handling I
   c) Inspecting or testing I
   d) Production planning I
   e) Receiving, storing, shipping . . O
   f) Devising, producing jigs and fixtures I
5. Management and staff I

Transporting:
1. Marine . . . . O
2. Motor truck . . . . O
3. All other . . . . O
4. Management and staff . . . . O

Designing, creating, developing, and researching:
1. Oriented toward extracting or producing I
2. Oriented toward processes or manufacturing I
3. Oriented toward products or marketing I
4. Oriented toward facilities . . . I
5. Oriented toward new creations or discoveries I
6. Auxiliary services I
7. Management and staff I

Marketing:
1. Sales representatives—Consumer . O
2. First-line supervision—Consumer . O
3. Sales representatives—Industry . O
4. First-line supervision—Industry . O
5. Customer servicing . . . . . O
6. Advertising and sales promotion . O
7. Market research and sales statistics . O

General administering:
1. Accounting and auditing . . . I
2. Financial, insurance, tax . . . O
3. Economics, planning, budgeting . I
4. Credit and collections . . . . O
5. Personnel I
6. External relations . . . . . O
7. Purchasing . . . . O
8. Traffic . . . . O
9. Office services I
10. General management auxiliary services I
11. Operations improvement
    a) Industrial engineering . . . I
    b) Operations research I
    c) Systems and procedures . . . I
    d) Scientific and technical programming and coding I
12. Tabulating and electronic computing I
13. Legal and secretarial . . . . . O
14. General management I
15. Specific accessory functions . . . I

TABLE 1

Industry	No.	Regression Equation	*r*
Aircraft	8	$9.56+.3628\,x$	.97
Chemicals	9	$11.07+.2152\,x$	.79
Drugs	8	$3.79+.2795\,x$	.92
Electrical machinery	7	$4.70+.4225\,x$	.89
Electronics	9	$6.41+.3864\,x$	.96
Fabricated metal products	5	$9.32+.1544\,x$	.63
Food	6	$8.96+.1582\,x$	.80
Machinery, except electrical	10	$9.01+.2096\,x$	.87
All industries*	62	$9.36+.2259\,x$	.80

* The all industries regression line was obtained by grouping the values of volume and surface for each of the sixty-two firms without reference to industry classification.

The data for each firm in each industry were plotted and a least-squares linear regression line fitted. The cube root of the inside staffing appears on the ordinate and the square root of the outside staffing appears on the abscissa. The results appear in Figures 1 through 8 and in Table 1.

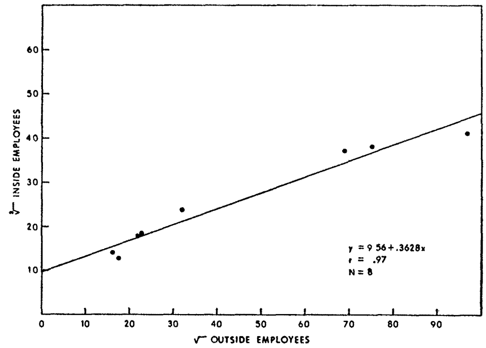

FIG. 1.—Aircraft

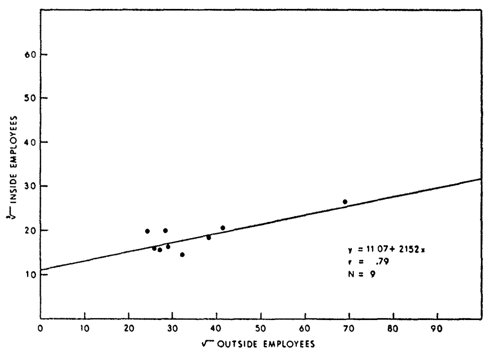

FIG. 2.—Chemicals

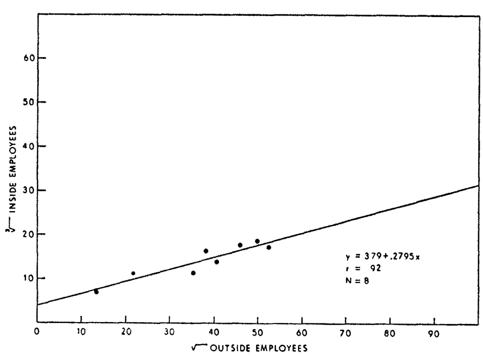

FIG. 3.—Drugs

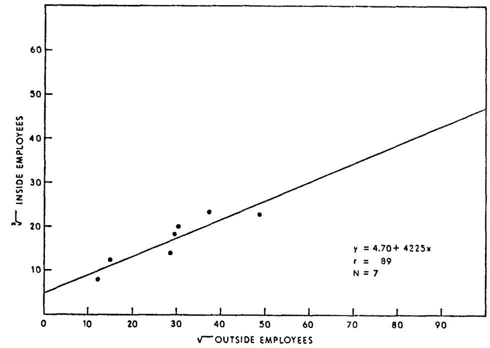

FIG. 4.—Electrical machinery

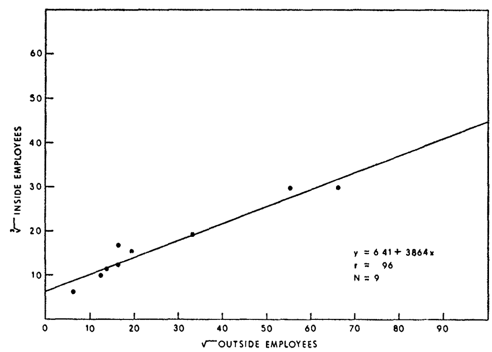

FIG. 5.—Electronics

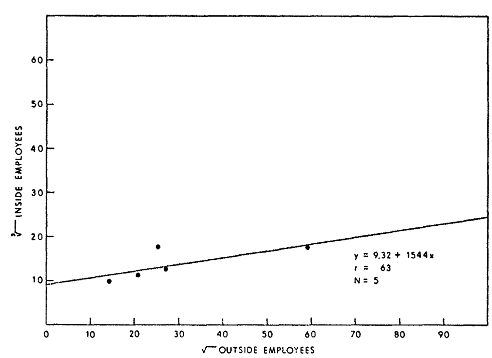

FIG. 6.—Fabricated metal products

The relationship of the cube root of volume and the square root of surface for each industry appears to be linear and in most cases with high correlations. The correlations range from .63 to .97 with a median of .88. The correlation coefficients of two industries fall within the range of correlations recorded by Haire for the four firms used in his study (.95–.99). The over-all relationship for all the firms revealed a correlation of .80 (Fig. 9).

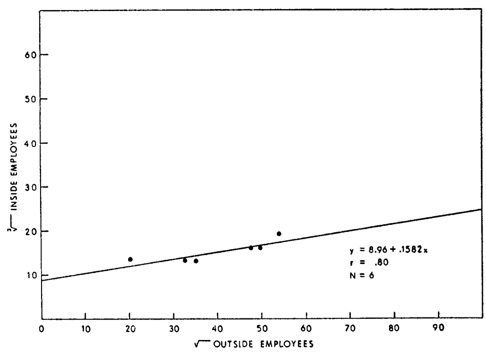

Fig. 7.—Food

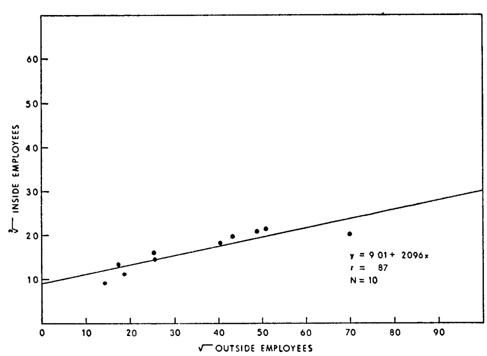

Fig. 8.—Machinery, except electrical

We see then that the square-cube relationship is consistent among firms of varying size within specific industries as well as within the total population of firms studied. The slightly higher correlations within industries (r = .88) contrasted with the total sample of firms from all industries (r = .80) suggests that there is greater homogeneity of organizational accommodations to the environment within specific industries than in industry in total. This tends to support one of the assumptions behind this study, namely, greater homogeneity of environment within industries than for all industries grouped together.

Let us now consider our question regarding differences among industries.

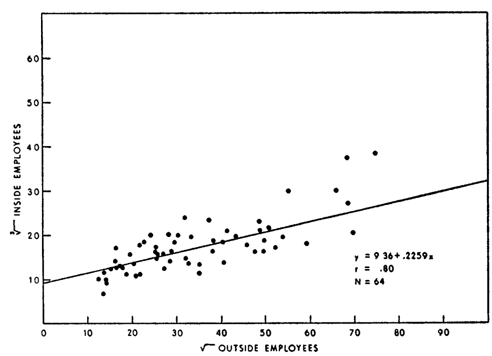

Fig. 9.—All industries

The slopes of the regression vary from .1582 to .4225. The smaller the slope, of course, the greater proportion of outside personnel to inside personnel. The regression equation does not mean, however, that this linear expression will be the precise geometry of growth for firms in these different industries over any prolonged period of time. What they do suggest is that the relationship of internal to surface personnel bears a consistent and linear relationship for firms of varying size within a given industry at a given point in time.

Are there differences in the slopes of the industry regression lines? Utilizing analysis of covariance, the null hypothesis that all slopes were equal was rejected at the .05 level of significance ($F = 2.22$, degrees of freedom = 7, 46). There are, therefore, statistically significant differences among the slopes of industry volume$^{1/3}$–surface$^{1/2}$ lines (see Table 1).

The question now posed deals with understanding the factors related to differences in slope among industry groups. We would suggest that there should be quantifiable data that give some common explanation for industries with similar regression line slopes as well as differing slopes. For example, industries having similar low slopes should have some common characteristics as should other industries with similar high slopes. Conversely, disparate industry groups should have certain differentiating characteristics as well.

TABLE 2

RANK-ORDER CORRELATIONS BETWEEN INDUSTRY VOLUME$^{1/3}$–SURFACE$^{1/2}$ REGRESSION LINE SLOPES AND MANPOWER PROPORTIONS

Function	Correlation
1. Production workers	−.27
2. Manufacturing	−.05
3. Designing, creating, developing, researching	.72*
4. Marketing	−.35
5. General administration	.07

* Significant at 5 per cent, $\rho = .71$. It is recognized that the probability of finding at least one correlation significant at the 5 per cent level purely by chance is .23.

The manpower composition of a firm, in terms of the functions performed and their relative staffing size, should give a fairly accurate description of organizational response to the environmental forces the firm must face to survive and to succeed. The pattern of proportional manpower allocation to different functions might then be looked upon as an organizational or manpower accommodation to the environment. We would expect differences among individual firms in the specific form of this accommodation. In addition, we should find some commonality among firms within specific industries with regard to specific patterns of manpower allocation. An examination was made to determine differences in manpower distributions.

For each industry, manpower profiles by major functional area are available—that is, the median by industry of the proportional staffing in each firm of the following broad functions to total staffing:

1. Production workers
2. Manufacturing—including production workers and manufacturing services and staff such as quality control, shipping and receiving, maintenance, etc.
3. Designing, creating, developing, and researching
4. Marketing—including sales, customer service, market research, and advertising
5. General administration—including what is generally referred to as staff or administrative overhead

If the slopes of industry regression lines indicate similarities or differences in the total environment in which these industries operate, and the internal structure of the firm reflects these differences, then it should follow that some differentiation in manpower profile would correlate with different regression line slopes. We are suggesting that there should be manpower allocation patterns which are related to industry regression line slopes.

The industry regression line slopes were ranked and correlated with the ranked proportion of manpower in each of the six major functions noted above (Table 2). There is a significant (5 per cent level) rank-order correlation of .72 between industry regression slopes and proportional staffing in designing, creating, developing, and researching. Correlations on the remaining functional groupings were not significant.

Using manpower data on major functional breakdowns, therefore, discloses only one significant pattern of manpower allocation—although, no doubt, there are many more should more refined functional groupings be utilized. We can say that for those industries with steeper regression line slopes (i.e., greater proportion of inside to outside employees) one characteristic of their internal accommodation to their environment is the proportionally greater staffing of research personnel, presumably a response to a need for research results to sustain or secure corporate success.[3]

This may seem like a tautology—industries with steeper regression line slopes (those that have a greater proportion of inside to outside employees) have more inside personnel in research and creating functions. In reality this is an important finding for two reasons. The first is that the finding is not a simple tautology since there are a number of other inside groups that might account for this greater proportion—for example, administrative, production, etc. Second, in terms of predicting future manpower complement, in steep-slope industries the hiring of ten additional research personnel might imply future hiring of X outside personnel, while in low slope industries, hiring ten research personnel might imply hiring $X + Y$ outside personnel.

An examination of the regression equations discloses that all intercepts on the ordinate are positive. In terms of the model, positive intercepts on the y axis mean volume without surface. These values, from 3.79 to 11.56, tend to be larger than those reported by Haire (1 to 3). The variances between Haire's reported intercepts and the higher intercepts of all industries tested in this study may be the result of differences in definitions of surface and volume employees or the character of the industries studied. On the other hand, the form of industrial organization is such that conceptually, as well as practically, it is impossible to have an absence of either inside or outside functions. Furthermore, the cross-sectional nature of this study may indicate valid relationships between firms of varying size within an industry but have limited validity when applied to an organization significantly smaller than any on which data were collected.[4]

In conclusion, we feel that several additional investigations are suggested.

1. Is the model appropriate for other industries, and on expanded samples of industries used in this study?
2. Are there other quantifiable indexes of manpower allocation patterns that relate to regression line slopes? For example, we have dealt with the number of employees only. Would measures of quality or value and importance (derived from average salary) have greater operational meaning for this concept than mere head count?

[3] We do not believe this conclusion is sufficient to substantiate Harbison and Hill's hypothesis that relative size of staff overhead is related to rate of innovation in product, process, or organization. Nonetheless it points in this direction (see Samuel E. Hill and Frederick Harbison, *Manpower and Innovation in American Industry* [Princeton, N.J., 1959], pp. 53 ff.).

[4] The authors are indebted to Antelman, of the University of Chicago's Graduate School of Business, for suggesting that the true relationship of volume$^{1/3}$–surface$^{1/2}$ is curvilinear rather than linear. The linear approximation leads to a positive intercept while a curvilinear relationship could conceivably go through 0, 0. Over the range of size firms studied, the linear approximation appears to be an appropriate fit even if a curvilinear regression were true. If a curvilinear relationship were true, we could expect firms of very small and very large surfaces to fall below the linear approximation. Antelman points out that one would also expect that as the minimum- or maximum-sized firm in terms of surface increased, the intercept would increase. The rank correlation between intercepts and minimum surface is .75, that between intercepts and maximum surfaces is .76. Hence, the suggestion of curvilinearity may have validity.

3. Are there any significant differences in innovational character, financial characteristics, etc., among industries as well as between firms that fall above and below the standard error about the regression line for that industry?

In summary, we suggest that the extension of Haire's modified square-cube law is a reasonable and consistent description of industrial organizational composition among firms of varying size in different industries. We would further conclude that the relationship of inside to outside personnel varies significantly among industries, and this variance, in turn, is a reflection of environmental differences and the effects of such environmental differences on organizational composition. Lastly, we have been able to isolate one characteristic of industries in relation to the volume$^{1/3}$–surface$^{1/2}$ regression line slopes; namely, a positive correlation with the proportion of total staffing engaged in research.