Organizational structure and R&D efficiency

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Abstract:

This paper compares innovative efficiency as proxied by a measure of R&D efficiency, between firms with organic and mechanistic R&D organizational structures. The results of the study support the hypotheses that organic structures experience greater efficiency in basic research, process-related R&D and long-term R&D activities than do mechanistic structures.

Keywords: R and D | organizational structures | efficiency

Article:

I. INTRODUCTION

One of the major paradigms of the innovation literature is that organic organizations, those more open to individual initiative and discretion, are more likely to be innovative than mechanistic organizations (Burns and Stalker, 1961). If so, and if innovation strategy is an important competitive dimension, then firms may look toward an internal reorganization as one potential source for increased innovation efficiency, and perhaps even increased market share, in those contexts where innovative behaviours are desired.

Early students of innovation held the belief that organic structures will always lead to greater innovativeness. Recent studies, however, indicate that this is not always the case (Zmud, 1982). Mechanistic structures can induce greater innovative behaviours, particularly when the innovative activity of concern is not necessarily viewed as being advantageous to the interests of a number of an organization's members.

The question naturally arises, then, whether organic structures should generally lead to greater innovativeness within an R&D group. Very little empirical work, however, exists on the relationship between organizational structure, a term we define to refer to information flows and decision-making channels, and the innovative behaviour of R&D groups. Relatedly, Fischer and Behrman (1979) and Link (1985) found that centralized R&D groups exhibit more of a scientific and long-term orientation in their research efforts than do decentralized groups. Also, Allen (1977) and Link and Zmud (1984) have shown that organic organizations make relatively more use of external sources of R&D intelligence than do mechanistic organizations. Still, these inquiries have only indirectly examined the organizational structure/innovativeness relationship.

This paper compares the innovative efficiency, as proxied by a measure of R&D efficiency, between firms with organic and mechanistic R&D organizational structures. The framework for this analysis is presented in Section II. In Section III the empirical analysis is discussed and summary remarks are in Section IV.

II. THE ANALYTICAL FRAMEWORK

A. The Theoretical Model

A model frequently used in the R&D literature for estimating the rate of return to R&D spending, that is R&D efficiency, is based on a three-factor Cobb-Douglas production function written as:

$$\text{(1)} \qquad Y = A_0 e^{\lambda t} L^{\beta} K^{1-\beta} T^{\alpha}$$

where Y is output; A_0 is a constant; λ is a disembodied rate of growth parameter; t represents time; L, K and T are inputs of labour, physical capital and technical capital respectively; and β and α are output elasticities. (The theoretical justification for this model is well documented For example, see Griliches (1979) or Link (forthcoming) for a detailed discussion of its theoretical merits and widespread empirical use.) There are constant returns to scale only with respect to physical capital and labour.

Differentiating equation (1) with respect to time, and defining total factor productivity growth as the percentage change in output not attributable to percentage changes in physical capital and labour, *ρ:*

$$\text{(2)} \qquad \rho = \dot{Y}/Y + \beta(\dot{L}/L) - (1-\beta)(\dot{K}/K)$$

$$\dot{Y} = dY/dt$$

$$\dot{L} = dL/dt$$

$$\dot{K} = dK/dt$$

which leads to:

$$\text{(3)} \qquad \rho = \lambda + \phi(I_T/Y)$$

where $\phi = (\partial Y/\partial T)$ is the marginal product of technical capital and where $I_T = \partial T/\partial t$ is the net private investment of the firm into technical capital, T. When I_T is approximated by a firm's total R&D investment expenditure, then ϕ can be interpreted as the rate of return to R&D, or our measure of R&D efficiency (Link, 1980).

B. The Effects of Organizational Structure on R&D Efficiency

In order to investigate the relationship between organizational structure and R&D efficiency, using a stochastic version of equation (3), the composition of R&D spending must be taken into account. There is no reason to believe that innovative efficiencies resulting from improved information flows and from more open decision-making channels will be realized equally across all types of R&D projects. In other words, while it is true that a single organizational structure characterizes the entire R&D group, it is not necessarily true that the internal efficiencies associated with that structure impact on different R&D projects in the same way.

The heterogeneous nature of activities commonly grouped under the rubric of R&D spending can be discerned by examining R&D by its character of use. Perhaps the most common breakdown of R&D spending is between basic research, applied research and development, categories fostered by the National Science Foundation in the 1950s. (See National Science Foundation (1983) for precise reporting definitions of these three categories of spending.) Other categories of spending that more closely correspond to industrial project classifications are R&D spending on products versus processes, and on long-term versus short-term activities.

We expect the organizational structure of an R&D group to affect R&D efficiency differentially across different categories of R&D spending (Allen, Tushman and Lee, 1979). For example, basic research should be more efficiently undertaken in an organic organizational structure than in a mechanistic structure. Basic research not only is characterized by risk, as is all research, but it is also characterized by uncertainty. This uncertainty exists due to the exploratory nature of basic research efforts, the lack of standards or prototype methodologies, and the absence of market signals regarding efficient input mixes, the timing of product introductions, and competitive rivalry. Also, the output from basic research ventures is difficult to define, or in some situations difficult to recognize at the time of discovery. Information flows which enhance, rather than inhibit, creative ideas and which encourage investigative searches for related knowledge beyond the confines of the R&D group are requisite for reducing the uncertainty component of basic research, and hence for increasing its potential success. An organic organizational structure encourages such information flows by relaxing restrictions on both the nature of the projects individual scientists undertake and the communication networks in which these scientists participate (Ouchi, 1979; Wilson, 1966; Zaltman, Duncan and Holbek, 1973).

In contrast, mechanistic structures may be more conducive of successful product development. The success of development-related ventures is often maximized when precise evaluative criteria and marketing strategies are designed and implemented. This implementation often requires a chain of authority that helps to insure the one way flow of effort and, to a certain extent, information: ideas → prototypes → development → marketing. Excessive individual freedom may slow down this process or lead to tangential projects. Likewise, alternative sources of R&D intelligence beyond the R&D group are less necessary than in basic research ventures because of the proprietary nature of new products. Mechanistic organizational structures, as they limit individual initiative, have been shown to restrict dysfunctional information flows (Organ and Greene, 1981) and to induce a reliance on prescribed, rationalized decision processes (Rowe and Boise, 1974).

Similar arguments, though not as strong, can also be made for differential relationships between organizational structure and the product versus process and short-term versus long-term categories of R&D activity. First, product innovation involves the creation of new products or services that externally shift or expand an organization's domain, while process innovation involves the introduction of new methods, procedures or requirements for shifts in individual responsibilities and behaviours within existing domains (Zmud, 1982). Product innovations are thus more likely to impact on organizational resource allocation patterns and, hence, impact on the vested interests of organizational members. As a result, we might expect organic organizations to experience greater efficiency with process rather than product R&D activities. Second, short-term R&D is by nature more focussed than long-term R&D. As a result, the directing and channelling of individual behaviours that tend to occur in mechanistic organizations might be expected to produce greater efficiency with short-term R&D than with long-term R&D.

We therefore hypothesize that firms with organic organizational structures will experience greater efficiency in basic, process, and long-term R&D activities than will firms with mechanistic structures, *ceteris paribus.*

C. The Empirical Model

These hypotheses are tested empirically from stochastic versions of equation (3). The regression equations estimated are:

(4a) $$\rho = \mathrm{a}_0 + \mathrm{a}_1(\mathrm{BR/Y}) + \mathrm{a}_2\mathrm{D}(\mathrm{BR/Y}) + \mathrm{a}_3\big((\mathrm{AR}+\mathrm{DEV})/\mathrm{Y}\big) + \mathrm{a}_4\mathrm{D}\big((\mathrm{AR}+\mathrm{DEV})/\mathrm{Y}\big)\mathrm{e}_1$$

(4b) $$\rho = \mathrm{b}_0 + \mathrm{b}_1(\mathrm{PROC/Y}) + \mathrm{b}_2\mathrm{D}(\mathrm{PROC/Y}) + \mathrm{b}_3(\mathrm{PROD/Y}) + \mathrm{b}_4\mathrm{D}(\mathrm{PROD/Y})\mathrm{e}_2$$

(4c) $$\rho = \mathrm{c}_0 + \mathrm{c}_1(\mathrm{LT/Y}) + \mathrm{c}_2\mathrm{D}(\mathrm{LT/Y}) + \mathrm{c}_3(\mathrm{ST/Y}) + \mathrm{c}_4\mathrm{D}(\mathrm{ST/Y})\mathrm{e}_3$$

where ρ represents total factor productivity growth; the constant terms, a_0, b_0 and c_0, correspond to the disembodied rate of growth parameter, λ; and the error terms, e_i, are assumed random and normally distributed. The independent variables represent expenditures on various categories of R&D spending: basic research (BR), applied research and development (AR+ DEV), process-related R&D (PROC), product-related R&D (PROD), long-term R&D (LT), and short-term R&D (ST). The variable D is binary to distinguish organic structures from mechanistic structures.

III. THE EMPIRICAL ANALYSIS

A. The Data

Equations (4a), (4b) and (4c) were estimated using published data from Compustat and survey data on R&D spending and organizational structure. The sample has 107 firms and was limited by the availability of survey R&D data, as discussed below.

Total factor productivity growth, ρ, between 1977 and 1981 (the full time period for available survey data) was measured by a two-stage process. First, an index of residual growth, $g_t = 1nY_t - \beta 1nL_t - (1-\beta)1nK_t$, was calculated for each firm, *t* = 1977–81. Then, following Mansfield (1980), among others, ρ in equation (3) was measured as the slope coefficient from a regression of g_t on trend for each firm. In these calculations output was measured as net sales defined as gross sales and other operating revenue less discounts, returns and allowances, deflated by the Bureau of Labour Statistics' industry specific producer price index. Labour was represented by the total number of employees as reported to its stock holders. Physical capital was approximated by the value of gross plant representing tangible fixed property such as land, buildings and equipment, deflated by the Bureau of Economic Analysis' implicit price index for non-residential gross private investments. The average share of labour in total sales over the period was estimated as the total labour expenditures of the firm in 1979 per unit of 1979 sales. For those firms not reporting labour expenditures to Compustat, labour's share was computed using the product of the average 1979 annual wage in each firm's industry as reported by the Bureau of the Census and the total number of 1979 employees in the firm.

The R&D data came from a survey of R&D vice-presidents of 146 U.S. manufacturing firms, conducted by the authors under the sponsorship of The National Science Foundation. Complete data for estimating equations (4a), (4b) and (4c) were available for 107 firms. Although not a random sample of U.S. manufacturing firms, it is an important sample. The firms account for nearly 30 per cent of all company-financed R&D spending during 1981: over 80 per cent of the firms spent more than $10 million on R&D in that year. (A more complete discussion of the survey methodology is in Bozeman and Link (1983)). For all firms the reported basic expenditures plus applied research and development expenditures, process-related R&D expenditures plus product-related R&D expenditures, and long-term R&D expenditures plus short-term R&D expenditures equal their total 1979 R&D expenditures.

The binary variable, D, equals '0' for those firms whose R&D group is characterized by an organic organizational structure and '1' for firms with a mechanistic structure. We developed this variable from information obtained in the survey. Each vice president was asked to respond in agreement or disagreement to the following two questions:

'In the R&D group:

- do ideas tend to originate at the bottom and move up rather than originate at the top and move down?
- does decision making tend to occur horizontally rather than vertically?'

Responses were measured dichotomously. A 'yes' response means that the item reflects the respondent's R&D group. Each firm's R&D structure was then defined by us to be organic when a 'yes' was recorded on *both* responses, that is firms with an organic structure exhibit both a bottom-up flow of ideas and a horizontal decision making pattern.

Descriptive statistics for these survey variables are in Table 1.

Table 1. Descriptive statistics on the survey R&D related variables n = 107

Survey variables	**Mean survey response**
% R&D expenditure going to basic research	4.51%
% R&D expenditure going to process & related research	39.03%
% R&D expenditure going to long-term research	21.17%
Organic structure	0.31

Additional information about this sample is available from the authors.

B. The Regression Results

The least-squares regression results from equations (4a), (4b) and (4c) are reported in Table 2. They conform, in part, to the hypotheses stated above. (Alternative specifications with the organizational structure binary variable interacted with the intercept term were also estimated; however, the estimated coefficients were insignificant. The single intercept term specification was chosen).

Table 2. Estimated regression results from equations (4a), (4b), (4c) (t-statistics in parentheses)

	(4a)	**(4b)**	**(4c)**
(BR/Y)	3.17 (3.92)**	—	—
D (BR/Y)	–1.52 (–2.71)**	—	—
((AR+DEV)/Y)	0.13 (2.01)*	—	—
D (AR+DEV)/Y	0.02 (2.13)*	—	—
(PROC/Y)	—	0.67 (2.59)**	—
D (PROC/Y)	—	–0.17 (–1.99)*	—
(PROD/Y)	—	0.21 (2.03)*	—
D (PROD/Y)	—	0.09 (2.41)*	—
(LT/Y)	—	—	0.23 (2.07)*
D (LT/Y)	—	—	–0.06 (–1.87)
(ST/Y)	—	—	0.09 (2.33)*
D (ST/Y)	—	—	–0.001 (–0.81)
R^2	0.57	0.49	0.32

* significant at .01 level
** significant at .05 level

The estimated coefficient on the basic research term, (BR/Y), is positive and highly significant and that on the interaction term, D(BR/Y), is negative and significant. These findings suggest that the efficiency of basic research is greater in firms with organic structures (D=O) than in firms with mechanistic structures (D=1). Similarly, the estimated coefficients on the applied research plus development terms are significant: the positive coefficient on the interaction term suggests greater efficiency in this type of R&D activity within mechanistic structures.

Organic structures appear to be more efficient than mechanistic structures in process-related R&D, but less efficient in product-related R&D. The interaction term on process-related R&D, D(PROC/Y), is negative and significant: the interaction term on product-related R&D, D(PROD/Y), is positive and significant.

Finally, the negative interaction term on long-term research suggests greater efficiency in organic structures; however, the difference is only marginally significant, in a statistical sense. There does not appear to be any difference in the efficiency of short-term R&D between the two defined structures.

IV. INTERPRETATION AND CONCLUSIONS

The policy issue stemming from this research is:

> Should R&D groups look toward internal reorganization as a potential source for increased R&D efficiency?

The empirical results presented here support such a proposition. Any such reorganization, however, must consider the nature of the R&D activities undertaken by an R&D group.

The paper's basic hypothesis, that organic organizational structures will lead to greater R&D efficiency where individual innovativeness is a desired behavioural quality, was supported most strongly when R&D activity was categorized on a basic versus applied/development scale. Such an outcome was expected given the unfocussed nature of, and the high level of individual innovativeness required in basic research, and the focussed nature of, and moderate level of individual creativity desired in applied or development research. A general prescription that basic research is facilitated by a more organic structure and that applied research and development is facilitated by a more mechanistic structure seems to be in order.

That organizational structure would have a different effect on R&D efficiency for process versus product R&D activities was also supported, though not as strongly. The argument behind this relationship was more tenuous than that regarding the basic versus applied/development dichotomy. An organic structure might very well find an R&D group's members able to improve a target organization's work processes in an open-ended manner. Product development, however, would seem to benefit from a more focussed, but still creative, effort that carefully intertwines market needs with technological advances but only after an organizational receptiveness for such an effort has been established. Again, a general prescription that process R&D is facilitated by a more organic structure and that product R&D is facilitated by a more mechanistic structure seems warranted.

Weak support was evidenced for a beneficial relationship between organic structures and long-term research. The study's thesis did not hold, however, for short-term research. As the nature of the R&D activities that might be included within either a long-term or short-term categorization can be quite diffuse, these findings were not that surprising. The association between organic structures and long-term greater R&D efficiency seems to support the paper's hypotheses. We hesitate to offer a general prescription regarding an appropriate organizational structure for either long-term or short-term R&D activities given our mixed findings.

These conclusions should be tempered by the limitations of the research methodology that was employed. Survey responses, particularly when the respondent is a vice-president, may only partially capture organizational realities as we have defined them. Further, the reliability and validity of the instrument used to measure organizational structure has not been assessed. As a consequence, further research is needed to validate the results that were obtained. Still, the overall strength of these findings does suggest that the study's methodology is capturing phenomena relevant to the paper's basic thesis.

Given that our findings are valid, further research should also begin to explore the effectiveness of alternative managerial strategies for creating appropriate organizational structures for R&D groups. What can be done to create more organic or more mechanistic organizational structures? The works by Rickards and Bessant (1980) and Fischer and Farr (1984) that seek to identify important facets of an R&D climate may serve as a starting point for such a research agenda.

Efforts aimed at the reorganization of R&D groups that are performing at less than desirable levels may very well be an important managerial lever. However, additional research toward a better understanding of the appropriateness of (1) alternative structures given the nature of the R&D activities being performed, and (2) the effectualness of specific managerial strategies for establishing a certain structure, is required before definitive managerial prescriptions can be offered.

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