An Analysis of the Composition of R&D Spending*

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I. Introduction

Research and development encompasses a myriad of activities. Generally, research is the primary search for technical or scientific advancement, and development is the translation of such advancement into product or process innovations. The National Science Foundation has fostered an even finer breakdown: basic research, applied research, and development.[1] In practice, however, R&D is more heterogeneous than these three labels imply. The research fields associated with basic research include areas in both the physical and the biological sciences. Applied research and development projects relate to product groups as diverse as all the activities in the industrial sector. Nevertheless, most previous empirical studies of the microeconomic aspects of R&D have treated R&D spending as a single, homogeneous activity. Consequently, a generally acceptable set of variables has developed for explaining inter-firm *levels* of R&D spending, but virtually nothing is known about the determinants of the inter-firm *composition* of R&D.[2]

The focus of this paper is an empirical examination of the determinants of inter-firm differences in R&D expenditures, disaggregated by character of use. Virtually nothing is known about this topic. Link [15] and Mansfield [20] have analyzed the effect of firm size on the composition of R&D expenditures, but a systematic analysis of the allocative determinants has not yet been conducted. This paper attempts to fill that void.

The analytical model underlying this paper is formulated in Section II. The results of the statistical analyses are presented in Section III. Finally, some concluding remarks are offered in Section IV.

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1. Basic research represents original investigation for the advancement of scientific knowledge that does not have a specific commercial objective. Applied research represents investigation directed to finding new scientific knowledge that does have a specific objective — product-related or process-related. Development is that technical activity concerned with nonroutine problems encountered in translating research findings and general scientific information into products or processes [26].

2. Mansfield [18] and Link [16] have shown that the distinction between the level and the composition of R&D is important in assessing the contribution of R&D spending on productivity growth.

II. The Analytical Model

There have been numerous empirical studies of inter-firm differences in R&D spending. Although many variables have been considered as determinants of R&D, five are commonly analyzed: the firm's profitability, the extent of the firm's diversification, the concentration of the industry in which the firm sells its product, the amount of federal R&D received by the firm, and the firm's form of ownership control. The motivation for each of these variables is fairly well established and will only be summarized here.[3]

The importance of profitability as a determinant of R&D spending is predicted on the belief that R&D involves risk and uncertainty [4; 28], and as a result requires substantial and often prolonged financial support. Some [6] contend that current profits can be viewed as an indicator of the firm's liquidity or cash-flow. Since firms may prefer to finance their R&D internally, current profitability is perhaps a necessary requirement for developing and maintaining a sizeable R&D program. Others [24] view current profits as an indicator of future profits. Firms that have enjoyed previous success and expect it to continue may be more willing to undertake the financial risks associated with R&D.[4] On the basis of these arguments many have predicted that profits positively affect the level of a firm's R&D spending.[5]

Nelson's [27] pioneering study of the economics of basic scientific research stressed that the results of such research are often unpredictable. It is not unusual for technical knowledge to simply sit or to be used in the future as an additional research input: basic research is not intended to solve the immediate practical problems of the firm. Because of this characteristic, Nelson hypothesized that only diversified firms with broad technological bases, and with "their fingers in many pies" [27, 302], will find it profitable to engage in basic research since they are better able to market whatever inventions or discoveries result. Subsequent researchers [6; 22] have relied on this so-called diversification hypothesis to test the role of product diversification as a determinant of total R&D spending.[6]

Concentration is also frequently cited as a determinant of R&D spending. Empirical tests of this proposition are based on Villard's [36] corollary to Schumpeter [31] that concentrated industries do relatively more R&D. Only a few researchers have found statistical support for this proposition. Most conclude that the relationship is complex and perhaps even simultaneous [14; 29].

There is varied speculation about the impact of federal R&D on the firm's R&D activities. On the one hand, Hamberg [7] claims that new scientific knowledge resulting from federally-sponsored R&D enlarges the firm's scientific base and thus expands its

3. For a review of previous studies and for a more detailed discussion of these and other variables see Kamien and Schwartz [10] and Scherer [30]. Throughout this paper reference to a firm's R&D spending is understood to refer to its self-financed, as opposed to federally-financed, R&D.

4. An alternative interpretation is also possible [9]. Firms with small or falling profits may feel pressure to innovate as a competitive strategy; thus, they will increase their R&D outlays.

5. However, as Kamien and Schwartz [10; 11] point out in their literature reviews, empirical support for this proposition is mixed.

6. Grabowski [6] avers that so long as basic research is not a perfect substitute for applied research or development, Nelson's argument is generally applicable to total R&D spending. The only direct test of Nelson's hypothesis is by Link and Long [17].

opportunity set for additional R&D. Kendrick [12] and Tilton [35], on the other hand, suggest that federal R&D and private R&D may be substitutes in the firm's innovation process if, one, the output resulting from federal R&D can be internalized by the firm or if, two, federal obligations cause the firm to reach its capacity for technical operations.[7]

It has also been hypothesized that the firm's ownership form of control is related to its R&D spending. According to managerial theories, as popularized by Berle and Means [3], manager-controlled firms are relatively more risk averse than owner-controlled firms.[8] For this manager-related risk aversion argument to apply to R&D activity the nature of the risks involved must be clearly specified. There are at least two dimensions to consider: there is risk in undertaking too much R&D and failing, and there is risk in not undertaking enough R&D and thus losing market shares to more innovative firms. A priori, the net effect of these influences is unknown; however, the research of McEachern and Romeo [22] suggests that firms controlled by individuals outside of direct management undertake a defensive innovation strategy and are relatively more R&D intensive.

On the basis of these arguments, previous researchers have considered regression models where the firm's R&D intensity (*RD/SIZE*) is the dependent variable and the firm's relative profits (*PROF/SIZE*), its extent of product diversification (*DIV*), its industry's concentration (*CONC*), its receipt of federal R&D (*FRD/SIZE*), and its ownership form (*OWNER*) are the independent variables:

$$RD/SIZE = \alpha_0 + \alpha_1\, PROF/SIZE + \alpha_2\, DIV + \alpha_3\, CONC + \alpha_4\, FRD/SIZE + \alpha_5\, OWNER + \epsilon. \quad (1)$$

Usually, $\hat{\alpha}_1$, $\hat{\alpha}_2$, and $\hat{\alpha}_3$ are predicted to be greater than zero: no predictions are made on $\hat{\alpha}_4$ or $\hat{\alpha}_5$.

Here, we are concerned with the influence of these independent variables on the composition of R&D, that is on the percent of the firm's R&D allocated to basic research (*BR*), applied research (*AR*), and development (*D*):

$$BR = \beta_0 + \beta_1\, PROF/SIZE + \beta_2\, DIV + \beta_3\, CONC + \beta_4\, FRD/SIZE + \beta_5\, OWNER + \epsilon_a \quad (2a)$$

$$AR = \gamma_0 + \gamma_1\, PROF/SIZE + \gamma_2\, DIV + \gamma_3\, CONC + \gamma_4\, FRD/SIZE + \gamma_5\, OWNER + \epsilon_b \quad (2b)$$

$$D = \eta_0 + \eta_1\, PROF/SIZE + \eta_2\, DIV + \eta_3\, CONC + \eta_4\, FRD/SIZE + \eta_5\, OWNER + \epsilon_c. \quad (2c)$$

These alternative specifications allow for a more direct test of Nelson's diversification hypothesis, $\hat{\beta}_2 > 0$. Other than that prediction, there is no specific body of literature related to the determinants of R&D, disaggregated by character of use. However, one

7. The empirical evidence is limited and mixed. Shrieves's [33] findings suggest crowding out of private R&D by federal R&D; however, the analyses of Leonard [13], Levin and Reiss [14], Link [15], Mansfield [19], Scott [32], and Terleckyj and Levy [34] can be interpreted as support for complementarity.

8. Simply, hired managers are more risk averse than owners since they do not internalize the benefits from successful risk taking but do internalize the costs from unsuccessful risk-taking activities. The hired manager benefits from successful risk-related ventures only to the extent that he is a stockholder and that successful ventures result in higher profits and stock prices: unsuccessful ventures may result in the manager's losing his job. This risk aversion tendency is often attributed to Baumol [1] and Monsen and Downs [23]; however, its origins can be traced at least to Beard [2] and Gordon [5].

additional hypothesis is posited; $\hat{\beta}_1 > 0$. This hypothesis is based on the assumption that basic research is characteristically more uncertain than either applied research or development, although there is risk associated with all three categories of spending. Therefore, since profits are assumed requisite for the internal financing of R&D on the basis of the associated risks and uncertainties, then it may be that profits are relatively more important for the financing of basic research than for applied research or development *ceteris paribus*.

III. The Statistical Analysis

Equation (1) and equations (2a)–(2c) were estimated using data corresponding to a sample of 275 U.S. manufacturing firms. The sample is limited to those firms for whom data on the composition of R&D are available.[9] These 1977 percentages are the dependent variables in equations (2a)–(2c). For equation (1), 1977 R&D expenditures (*RD*) are available from *Compustat*. These figures are divided by the firm's net sales (*SIZE*), defined as gross sales and other operating revenue less discounts, returns, and allowances, also reported by *Compustat*. Both sets of data are measured in millions of dollars.

Firm profits (*PROF*) are measured as profits after taxes and dividends, lagged one year, as reported in *Compustat* (in millions of dollars).

The extent of product diversification (*DIV*) characterizing each firm is represented by the number of four-digit SIC industries in which the firm and its subsidiaries operate. The data come from the Standard & Poor's *Register of Corporations*.[10]

A four-firm concentration ratio (*CONC*), corresponding to the four-digit industry in which each firm produces, approximates the market power. These data come from the 1972 *Census of Manufacturers*.[11]

9. The parent population was the manufacturing firms listed in the 1977 Fortune 1000. All firms were surveyed. A total of 384 firms responded to the initial and follow-up survey; however, only 275 were willing to participate. The other 109 firms responded that the requested information is confidential or that company policy prohibits participation in surveys even when confidentiality of the information is guaranteed. The 275 firms in the sample accounted for 65.3 percent of total 1977 net sales in manufacturing. To my knowledge, this set represents the most comprehensive collection of data reported in the literature on the composition of R&D. Other descriptive statistics about the sample are available from the author by request.

There is a fundamental question about the validity of these firm specific responses that needs to be addressed. This question is with regard to the general appropriateness of the categories basic research, applied research, and development. Since the 1950s the National Science Foundation has used these labels in an attempt to compare R&D expenditures in all sectors of the economy using one common set of definitions. Nason, Steger, and Manners [25] have considered, in particular, whether the label *basic research* is appropriate for survey purposes and have concluded that the label does have validity. Although most firms categorize R&D differently, they are, according to Nason, Steger, and Manners, familiar enough with National Science Foundation reporting that the terms are meaningful. Presumably, that would also be the case for the terms *applied research* and *development*.

10. No attempt was made to weight this index by the percentage of the firm's sales in each of these four-digit SIC industries. Since the output of basic research is by definition unknown *a priori*, the incentive to undertake such research is provided by the potential to use whatever results. Firms can expand their market share through successful research; thus, it may be the number of markets serviced by each firm that is relatively important. Grabowski [6] and McEachern and Romeo [22] measured DIV as the number of five-digit SIC product lines in which a firm produced. Those data, however, were last published in *Fortune's 1966 Plant and Product Directory*.

11. *Compustat* classifies each of the sample firms by an SIC industry code; however, these classifications are often at the three- and sometimes two-digit levels. In those instances the firm's four-digit classification was taken from information in the Standard & Poor's *Register of Corporations*.

Table I. Regression Results from Equations (1), (2a)–(2c): n = 275

	Dependent Variables			
Independent Variables	(1) *RD/SIZE*	(2) *BR*	(3) *AR*	(4) *D*
Constant	.027*	.007	.256	.728**
	(3.76)	(1.21)	(1.41)	(2.01)
PROF/SIZE	.258*	.153*	.695**	−.848
	(2.99)	(3.06)	(2.26)	(−1.13)
DIV	.0038***	.0022**	.0009	−.0031
	(1.72)	(2.27)	(1.05)	(−1.37)
CONC	.017	−.0041***	−.0007	.0048*
	(.87)	(−1.71)	(−.91)	(2.15)
FRD/SIZE	.094**	−.081***	−.005	.086*
	(2.01)	(−1.75)	(−1.59)	(2.31)
MC	−.0003	.009	.011	−.02
	(−.72)	(.43)	(.29)	(−.45)
OM	.0007	.004**	−.001	−.003
	(.41)	(2.14)	(−.51)	(−1.34)
R^2	.385	.462	.317	.401

* significant t-statistic at .01 level
** significant t-statistic at .05 level
*** significant t-statistic at .10 level

Data on federal R&D expenditures (*FRD*) received by each firm were also obtained from the survey and are in millions of dollars.[12]

The least-squares results, with t-statistics in parentheses, corresponding to equation (1) are reported in column (1) of Table I. These results correspond very well to those reported by others. Profitability, diversification, and federal R&D are significantly related to R&D intensity. The estimated coefficient on *PROF/SIZE* is positive and significant at the .01 level, the estimated coefficient on *DIV* is also positive, but is only significant at the .10 level. The receipt of federal R&D seems to complement the firm's R&D spending: the estimated coefficient on *FRD/SIZE* is positive and significant at the .05 level.[13] The *CONC* variable is not significantly related to R&D intensity. Similarly, the ownership control variables are not statistically important.

The least-squares results from equations (2a)–(2c) are reported in columns (2)–(4) of Table I.[14] As hypothesized, profitability and diversification are positively related to the

12. Approximately 29 percent of the survey respondents reported receiving federal R&D in 1976/77.

13. This finding suggests that a one dollar increase in federally-financed R&D increases company-financed R&D by 9.4 cents. Mansfield [19] reports that his and other studies find a similar complementary relationship between private and federal R&D.

14. Equations (2a)–(2c) were estimated by ordinary least-squares. Since $BR + AR + D = 1$, it follows that the error terms are related across the three equations as $\epsilon_a + \epsilon_b + \epsilon_c = 0$. However, no efficiency is gained from a seemingly unrelated regressions estimation since the independent variables are the same in equations (2a)–(2c).

percentage of R&D going to basic research: the estimated coefficient on *PROF/SIZE* is significant at the .01 level and on *DIV* at the .05 level. Industry concentration is negatively related to the basic percentage at the .10 level.[15] The results in equation (1) suggest that an increase in federal R&D increase private R&D: in equation (2), however, the estimated coefficient on *FRD/SIZE* suggests that this increase is primarily directed away from basic and toward development.[16] Finally, the estimated coefficient on *OM* is negative and significant at the .05 level. Whereas owner-managed firms are no more R&D intensive than firms with other forms of ownership, they are relatively more intense in basic than in applied research or development.

The only variable statistically related to the applied research percentage is *PROF/SIZE*. Its estimated coefficient is positive and significant at the .05 level. Apparently, profitability is a determinant of the research portion of a firm's R&D rather than the development portion.

In column (4), two variables are statistically related to the percentage of R&D allocated to development, *CONC* and *FRD/SIZE*. The estimated coefficient on each is significant at the .01 level.

Federal R&D expenditures can also be disaggregated by their character of use. My data allowed for a dichotomy between federal basic and federal applied plus development. When equations (1) and (2a)–(2c) were reestimated accounting for this division, the results indicated that the composition of federal spending does matter (results not shown). The positive relationship between *FRD/SIZE* and *RD/SIZE* and *D* is primarily a result of federal applied plus development expenditures. Alternatively, the *FRD/SIZE* to *BR* relationship reflects federal basic allocations.

IV. Concluding Remarks

It is well known that many different activities are classified under the rubric of R&D. However, few researchers have empirically taken this fact into account. To my knowledge, this study is one of the first to systematically analyze the determinants of inter-firm differences in the composition of R&D spending. This is an important step toward increasing our understanding of one factor that underlies technical advancement.

Still, the findings presented here should be viewed as preliminary and interpreted cautiously. The results are based on survey responses for only one year and likely are biased by subjective interpretation by the respondent. In addition, several of the independent variables considered are crudely measured (although are consistent with the state of the art). Other elements of market structure besides a four-firm concentration should be analyzed. These might include the extent of the firm's vertical integration or the extent of voluntary standardization in the industry. Also, there is room for improvement in the manner in which diversification is measured. Steps toward this end are already being considered by those analyzing the Federal Trade Commission's Line of Business Data.

15. This finding is consistent with Mansfield [20] who found a negative correlation between the industry percent of R&D allocated to basic and concentration.

16. Higgins and Link [8] also found empirical evidence of a reallocation of the firm's R&D as a result of increases in federal R&D funds.

Finally, other organizational factors besides ownership form may be related to both the level and the composition of R&D spending. Nevertheless, this study is viewed as a forward step toward understanding R&D activity in manufacturing.

The index of ownership control used here is developed following the work of McEachern [21; 22]. Each firm is classified into one of three categories: (1) externally-controlled — *EC* equals 1 if a party holds 4 percent or more of the common stock but is not part of management, and *EC* equals 0 otherwise; (2) manager-controlled — *MC* equals 1 if no single party owns 4 percent or more of the common stock, and *MC* equals 0 otherwise; and (3) owner-managed — *OM* equals 1 if the chief executive officer directly or beneficially owns 4 percent or more of the common stock, and *OM* equals 0 otherwise. In this trichotomy the owner-manager is presumed to be the least risk averse, coming closest to a classical entrepreneur: the externally-controlled firm is presumed to be the most risk averse, since an outside dominant stockholder is believed to have little knowledge of the firm's daily activities and hence may be myopic in his judgement.

References

1. Baumol, William J. *Business Behavior, Value and Growth*, rev. ed. New York: Harcourt, Brace and World, 1967.
2. Beard, Miriam. *A History of the Businessman.* New York: Macmillan Co., 1938.
3. Berle, Adolf A. and Gardiner C. Means. *The Modern Corporation and Private Property.* New York: Commerce Clearing House, 1932.
4. Gilpin, Robert. Prepared testimony in *Technology and Economic Growth*, Congress of the United States, Washington, D.C., 1975: 17-26.
5. Gordon, Robert A. *Business Leadership in the Large Corporation.* Washington, D.C.: The Brookings Institution, 1945.
6. Grabowski, Henry G., "The Determinants of Industrial Research and Development: A Study of the Chemical, Drug, and Petroleum Industries." *Journal of Political Economy*, March/April 1968, 292-306.
7. Hamberg, Daniel. *R&D: Essays on the Economics of Research and Development.* New York: Random House, 1966.
8. Higgins, Richard S. and Albert N. Link, "Federal Support of Technological Growth in Industry: Some Evidence of Crowding Out." *IEEE Transactions on Engineering Management*, November 1981, 86-88.
9. Horowitz, Ira, "Estimating Changes in the Research Budget." *The Journal of Industrial Engineering*, March 1961, 114-18.
10. Kamien, Morton I. and Nancy L. Schwartz, "Market Structure and Innovation: A Survey." *Journal of Economic Literature*, March 1975, 1-37.
11. ———, "Self-Financing of an R&D Project." *American Economic Review*, June 1978, 252-61.
12. Kendrick, John W. Prepared testimony in *Special Study on Economic Change*, part 2, Congress of the United States, Washington, D.C., 1978: 622-37.
13. Leonard, William N., "Research and Development in Industrial Growth." *Journal of Political Economy*, March/April 1971, 232-56.
14. Levin, Richard C. and Peter C. Reiss, "Tests of the Schumpeterian Model of R&D and Market Structure." Paper presented at the NBER Conference on R&D, Patents and Productivity, October 1981.
15. Link, Albert N. *Research and Development Activity in U.S. Manufacturing.* New York: Praeger, 1981.
16. ———, "Basic Research and Productivity Increase in Manufacturing: Additional Evidence." *American Economic Review*, December 1981, 1111-12.
17. ———, and James E. Long, "The Simple Economics of Basic Scientific Research: A Test of Nelson's Diversification Hypothesis." *Journal of Industrial Economics*, September 1981, 105-09.
18. Mansfield, Edwin, "Basic Research and Productivity Increase in Manufacturing." *American Economic Review*, December 1980, 863-73.
19. ———, "R&D and Innovation: Some Empirical Findings." Paper presented at the NBER Conference on R&D, Patents and Productivity, October 1981.
20. ———, "Composition of R&D Expenditures: Relationship to Size of Firm, Concentration, and Innovative Output." *Review of Economics and Statistics*, November 1981, 610-14.
21. McEachern, William A. *Managerial Control and Performance.* Lexington, MA: D.C. Heath, 1975.
22. ———, and Anthony A. Romeo, "Stockholder Control, Uncertainty and the Allocation of Resources to Research and Development." *Journal of Industrial Economics*, June 1978, 349-61.

23. Monsen, R. Joseph, Jr. and Anthony Downs, "A Theory of Large Managerial Firms." *Journal of Political Economy*, June 1965, 221-36.

24. Mueller, Dennis C., "The Firm Decision Process: An Econometric Investigation." *Quarterly Journal of Economics*, February 1967, 58-87.

25. Nason, Howard K., Joseph A. Steger, and George E. Manners. *Support of Basic Research by Industry.* Washington, D.C.: National Science Foundation, 1978.

26. National Science Foundation. *Research and Development in Industry, 1977.* Washington, D.C.: Government Printing Office, 1979.

27. Nelson, Richard R., "The Simple Economics of Basic Scientific Research." *Journal of Political Economy*, June 1959, 297-306.

28. ———, and Sidney G. Winter, "In Search of a Useful Theory of Innovation." *Research Policy*, 1977, 36-76.

29. Phillips, Almarin, "Patents, Potential Competition, and Technical Progress." *American Economic Review*, May 1966, 301-10.

30. Scherer, Frederic M. *Industrial Market Structure and Economic Performance*, 2nd ed. Chicago: Rand McNally, 1980.

31. Schumpeter, Joseph A. *Capitalism, Socialism and Democracy*, 3rd ed. New York: Harper and Row, 1950.

32. Scott, John T., "Firm versus Industry Variability on R&D Intensity." Paper presented at the NBER Conference on R&D, Patents and Productivity, October 1981.

33. Shrieves, Ronald E., "Market Structure and Innovation: A New Perspective." *Journal of Industrial Economics*, June 1978, 329-46.

34. Terleckyj, Nestor E. and David Levy, "Factors Determining Capital Formation, R and D Investment, and Productivity." Mimeo, National Planning Association, 1981.

35. Tilton, John E., "Research and Development in Industrial Growth: A Comment." *Journal of Political Economy*, September/October 1973, 1245-48.

36. Villard, Henry H., "Competition, Oligopoly and Research." *Journal of Political Economy*, December 1958, 483-97.