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MARKET STRUCTURE AND TECHNOLOGICAL PERFORMANCE IN THE FOOD MANUFACTURING INDUSTRIES

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PART I

INDUSTRY STRUCTURE AND TECHNOLOGICAL PERFORMANCE

CHAPTER 2. ECONOMIC HYPOTHESES RELATING FIRM AND MARKET STRUCTURE AND FIRM R & D

Hypotheses relating firm- and market-structure variables to firm research and development play a central role in modern industrial-organization theory. Firm size, advertising intensity, diversification, and market share are hypothesized to influence the level of firm research. Market concentration and the firm's product market are also potentially significant determinants of firm R & D activity. Concurrent with the development of these hypotheses, there has been a growth of applied econometric research to test and refine them. The extensive review article by Kamien and Schwartz (1975), the literature review in the leading industrial-organization textbook (Scherer, 1970) and the review by Weiss (1971) of the applied econometrics work in industrial organization provide a comprehensive overview of this research and need not be duplicated here.

Economic theory partitions firm research-and-development activity into several different categories. Schumpeter subdivided firm research and development into three stages: invention, innovation, and imitation or diffusion. Scherer characterizes these three stages as follows:

> **Invention . . .** is the act of conceiving a new product or process and solving the purely technical problems associated with its application.
> **Innovation . . .** involves the entrepreneurial functions required to carry a new technical possibility into economic practice for the first time—identifying the market, raising the necessary funds, building a new organization, cultivating the market, etc.
> **Imitation or diffusion . . .** is the stage at which a new product or process comes into widespread use as one producer after another follows the innovating firm's lead.[1]

It would, of course, be most interesting to estimate separate models for each of these stages and to examine how the structural variables have different impacts on invention, innovation, and diffusion. The available data on firm research and development—firm patents, research employees, and research expenditures—are indices of firm inventive activity. Thus, this study focuses primarily on the relationship between market structure and firm inventive activity.

Behr and Helmberger's analysis of research and development in the food-manufacturing sector of the U.S. economy (Imel, Behr and Helmberger, 1972), which is the only published econometric study of invention to focus on the food industries, is not discussed in the review articles mentioned above. This analysis estimated a cross-sectional, single-equation model with firm research-and-development expenditures divided by firm sales as the dependent variable. Market-structure data for the year 1963 were constructed for three different industry classifications: Census 4-digit (SIC) industries, a mixtures of 4- and 5-digit (SIC) industries and "reconstructed Census industries." Based on a theoretical model, the statistical problem of heteroscedasticity was handled in an innovative fashion.

Behr and Helmberger found that four-firm concentration had a significant positive effect on firm research intensity. Since only a linear term was estimated, it is impossible to determine if there was a critical value in this relationship. Firm diversification and the percent of the firm's sales that are not food-related were also found to have significant, positive effects. Firm size was not a significant explanatory variable. Since the dependent variable was research intensity, a nonsignificant size variable presumably implies that the relationship between firm size and the total firm R & D expenditures was approximately proportional. Their product-differentiation variable, which was the proportion of the firm's sales in consumer goods industries, was not significant.

FIRM SIZE

The size of the firm, measured in various ways, is the most popularly tested variable identified in the literature on firm invention and market structure.

There are several reasons why inventive activity may increase at an increasing rate with firm size. First, larger firms may be able to spread the risk of research-and-development work by engaging in a number of projects simultaneously. According to Scherer:

> Small firms place themselves in a dangerous position when they invest all their resources in a single innovative project whose prospects for technical and commercial success are far from guaranteed. This, combined with the risk aversion to which business managers and investors are supposedly prone, is said to discourage technical pioneering by small companies. The large corporation, on the other hand, can afford to maintain a balanced portfolio of R & D projects, letting the profits from successes more than counter-balance the losses from those that fail.[2]

The costs of research and development that represent an investment by the firm, and the returns on this investment must be compared with the alternative investments open to the firm. Investments cannot be evaluated solely on the basis of expected returns, however, since this ignores the variability in these returns. Considering the firm's research-and-development portfolio as a unit, what is the appropriate measure of the variance of this investment? Clearly, the firm is interested in the expected return and the variance of the return on research and development relative to the cost of the investment. Thus, if R_i is the return on the i^{th} R & D project in the firm's portfolio, and C_i is the cost of this project, then the variance of the firm's research-and-development investment in n projects is given by:

$$\text{(2-1)} \quad \text{Variance}\left(\sum_{i=1}^{n} R_i \Big/ \sum_{i=1}^{n} C_i\right) = \frac{\sum_{i=1}^{n} \text{Variance}(R_i) + \sum\sum_{i \neq j} \text{Covariance}(R_i, R_j)}{\left(\sum_{i=1}^{n} C_i\right)^2}$$

Suppose that the returns on projects are uncorrelated and identically distributed, and all projects have the same costs. Then the variance of the firm's research portfolio is given by:

$$(2\text{-}2) \qquad n \times \frac{\text{Variance (R)}}{(nC)^2} = \frac{\text{Variance (R)}}{nC^2}$$

Thus, if firms' reseach-and-development investments per unit of sales are constant across firm size, then the variance of the return of the firms' R & D investments deflated by research costs will decline as firm size increases.[3]

There are several objections or qualifications to this line of reasoning. It is unlikely, and the available empirical evidence does not support, the assumption that the average expense of a research project is independent of firm size. In fact, Scherer has argued that society maintains a wide range of firm sizes precisely because the cost of research projects undertaken by firms is correlated with size.[4] The costs of projects has approximately a Pareto distribution, he observes, with the expensive R & D projects limited to the largest firms in an industry. The history of invention is replete with examples of small enterprises unable to develop their work fully without utilizing the resources of the large corporation.[5]

Returns to firm research-and-development projects are likely to be correlated, since there are undoubtedly firm characteristics that help to determine the success of projects. In both the selection of particular problems and the actual research-and-development work, some firms will be more successful than others, resulting in a positive correlation between the returns on firms' research projects. Thus, while it is possible that the variance of the return of the firm's research-and-development portfolio declines with an increase in firm size, it does not seem likely that the reduction is large.

Capital market imperfections are a second reason to hypothesize that expenditures for firm research-and-development increase at an increasing rate as firm size increases. As mentioned above, there are numerous examples in the history of the invention where the cost of developing a project grows beyond the financial resources of the original inventor. Large corporations have played an important role in developing these very expensive inventions. In his study of important innovations by E. I. du Pont de Nemours & Co., Mueller found that only 10 of Du Pont's 25 most important product and process innovations were based on inventions by Du Pont scientists.[6] It appears that its vast financial resources gave Du Pont a comparative advantage in developing and marketing very expensive innovations.

Particularly in the food industries, it is possible to overstate this advantage. Examples of inventions that require development and marketing expenditures exceeding the financial capacity of moderate-sized firms in an industry are more often drawn from the electronics and aero-space industries than the food industries. Viewing project cost as a random variable with a Pareto distribution,[7] as suggested by Scherer,[8] we are interested in the percentage of the distribution with costs too high to be borne by the moderate-sized firms in the industry. This percentage is probably smaller for the food industries than for many other industries.

It cannot be concluded that financial constraints place no limitations on the research projects chosen by firms in the food industry. Doubtless there are R & D projects in the food industry with costs too high for any but the largest firms to bear. However, because the technological base of food R & D is relatively low, the costs of the bulk of food-research projects probably do not exceed the financial capabilities of moderate-sized food firms.

In the production of inventions, as in the production of any other economic good, the existence of minimum optimal scale (MOS) plays an important role in understanding the market behavior of firms. It is important to recognize that the MOS referred to here pertains to the research laboratory itself, rather than to the minimum size at which a firm can achieve minimum unit costs for its final products. Two factors determine the research MOS for the food-processing industries. First, the capital inputs must be intensively utilized for research costs to be at a minimum. The modern laboratory, employing expensive technical equipment, will not achieve minimum unit costs of invention unless its technical equipment is used to capacity. This suggests that for a given type of laboratory, there will be an optimal number of researchers and technicians to take full advantage of the reseach capital. From a practical point of view, the size of capital costs, as well as their indivisibility, plays an important role. If fixed costs are small relative to variable costs, then the reduction in average costs of research due to more intensive utilization of capital will have little practical significance.

Specialization of tasks among scientists, the second factor, may also determine the MOS for research in food-processing industries. If the research laboratory is so small that scientists cannot concentrate solely on the project in which their comparative advantage lies, then their efficiency will be reduced. Correspondingly, insofar as laboratory workers can pool their different fields of expertise, economies of scale in research will result. The economies possible from this specialization of labor probably increase with the level of technical sophistication of the research activity.

Large firms may have an advantage not only in inventing new products but also an advantage in marketing the products that they invent. Until they were discontinued in the early 1970s, discounts for quantity purchases of advertising time on television resulted in cost savings for larger firms relative to smaller firms.[9] In addition to these savings, large advertisers also received, and continue to receive, preferred-programming access. For an advertisement to be effective it must be shown when the target audience is watching television. Because of their superior bargaining power, firms with large advertising budgets receive the time slots that maximize the effectiveness of their advertisements.

Summarizing, there appear to be numerous reasons for hypothesizing that the costs of inventions fall as firm size increases. While many of the hypotheses relating reductions in the cost of invention to increases in firm size may be less applicable to the food-processing industry, they still establish an hypothesis to be tested empirically. There is one hypothesis, however, that suggests that firm inventive activity will increase less than proportionally with firm size. The decision to engage in any particular project must go through an established chain of command in the larger corporation, with the probability of approval declining as the number of links in this process increases. If p_i is the probability that the project will be approved at any decision-making stage of the corporation, then the probability that the project will be approved, assuming that there are k independent decision-making stages, is p_i to the k^{th} power. Since this clearly declines as k increases, the probability of approval for any given R & D project is probably smaller in the larger corporation.

This is not conclusive evidence that larger firms therefore do relatively less research work than small firms for two reasons. Researchers in larger corporations may choose projects with a higher value of p_i, the probability of the project being accepted. In fact, there is some evidence that this is the case since large firms specialize in the development and marketing stages of research.[10] At this point in the life of an invention, there is substantially less uncertainty about its commercial value than at earlier stages of development. Second, there are a variety of organizational structures available to the firm, some of which attempt to circumvent this very problem. For example, effective decentralization of the research-and-development laboratory will allow the large firm to choose research projects equal in risk to that of the smaller firm.

The discussion thus far has focused on hypotheses relating the *supply* of inventions to firm size, assuming that the firm's *demand* for inventions is independent of firm size. If new products are the output of the firm's research-and-development program, then this is a reasonable assumption. The value of inventions is determined by consumer demand for the products developed, and there is no reason to expect consumer demand to be correlated with firm size. Process inventions, however, have returns that are correlated with firm size. As Scherer points out:

> Finally, larger producers have an obvious advantage in making process innovations. A new process that reduces costs by a given percentage margin yields larger total savings to the company producing a large volume of output than to the firm whose output is small.[11]

MARKET POWER

Among modern economists, the association of market power and firm R & D activity can be traced to the writings of J.A. Schumpeter. Schumpeter's classic thesis is that perfect competition is incompatible with the optimal dynamic performance of the economy.

> What we have got to accept is that [the large-scale establishment or unit of control] has come to be the most powerful engine of [economic] progress.... In this respect, perfect competition is not only impossible but inferior, and has no title to being set up as a model of ideal efficiency.[12]

However, Schumpeter also recognized that too little competition might inhibit firm R & D.

> It is certainly as conceivable that an all-pervading cartel system might sabotage all progress as it is that it might realize, with smaller social and private costs, all that perfect competition is supposed to realize.[13]

Thus, Schumpeter holds that the possession of monopoly power is a *necessary* condition for the firm to engage in R & D, but not a *sufficient* condition—a point often overlooked by Schumpeter's disciples.

Schumpeter recognized that R & D is an unusually risky investment for the firm.[14] If the firm is unable to safeguard its inventions through devices like patents, temporary secrecy, and long-term contracts, all of which give the firm a temporary monopoly, then the firm will reduce its risk by purchasing or providing itself with insurance. The cost of the insurance must be covered by a price premium on the product or other products of the firm. If the firm operates only in competitive markets, then this cost can be borne only if the firm earns a subnormal return on capital.

The price premium that firms in noncompetitive markets may charge will reduce the risk of R & D investments in yet another way. This premium allows the firm to write off its R & D investments more rapidly. Firms treat R & D expenditures as expenses, not assets, so the costs of R & D are expensed in the year in which they are incurred. However, in its *ex post* analysis of R & D expenditures, management has the data to analyze R & D expenditures as assets. The more rapidly these assets are depreciated, the lower the probability that a new entry will leave the firm unable to recover its investment.

To Schumpeter, profits in excess of the opportunity cost of capital serve a valuable function. While few firms earn these very large profits, the example of those that do encourages investing capital in R & D. The "prizes" won by some capitalists may stimulate others to emulate the efforts of the winners.

Finally, Schumpeter believed that the firm will treat internally generated capital differently from capital that is externally attracted. Because of the risky nature of R & D, firms prefer to expense the cost of R & D out of present income rather than incur a liability. Firms in less-competitive markets have greater financial slack than firms in competitive markets. The former, therefore, have greater ability to expense R & D out of present income.

As quoted above, Schumpeter appreciated that increased market power does not *necessarily* stimulate firm investment in R & D. The management of the firm may be free to choose among a variety of goals for the firm, with profits being only one of many. Rather than aiming for maximum profits, the firm's management may be "satisficers;" minimum goals are established, and so long as the firm's performance attains these goals, no action is taken to modify the firm's behavior. Without the push of competition to force the firm to perform optimally, it has discretion over the size of its R & D outlays.

FIRM DIVERSIFICATION

Richard R. Nelson has advanced the hypothesis that firm diversification is positively correlated, *ceteris paribus,* with firm research-and-development activity.

> A broad technological base insures that, whatever direction the path of research may take, the results are likely to be of value to the sponsoring firm. It is for this reason that firms which support research toward the basic-science end of the spectrum are firms that have their fingers in many pies.[15]

For basic-science research, unanticipated research developments are more likely to lie in the firm's field of expertise if the firm is diversified. There is undoubtedly some basic-science research conducted in the research laboratories of food-processing firms.[16] Chemical research by the large meat-packing firms, such as Armour and Swift, may be one example. However, relative to their total research effort, the food-processing industry does little basic-science research.

While the focus of Nelson's hypothesis is firm basic-science research, the theory also applies to research-and-development activity to achieve new products and processes. Research of the latter type, which was shown in Chapter 1 to be the focus of food-processing firms, is characterized by substantially less uncertainty than basic-science research. However, this is a quantitative, not qualitative, difference since the diversified firm will still have an advantage in marketing unanticipated product developments or utilizing unanticipated process inventions.

The diversified firm can minimize the variance of the average return on its R & D projects by engaging simultaneously in a number of projects in product lines in which it has production and marketing expertise. As was shown in the discussion of hypotheses relating firm size to firm invention, the variance of the return on the firm's research-and-development projects declines as the number of projects increases. Since the diversified firm can engage in many research projects within those fields in which it has production and marketing expertise, it may enjoy a lower variance of the average return on its R & D investment. The extent of the reduction in variance will be determined by the covariance between projects. The firm whose projects are sufficiently diverse to be uncorrelated will enjoy the greatest advantage since inversely correlated returns on R & D projects seem unlikely.

TECHNOLOGICAL OPPORTUNITY

The concept of technological opportunity, introduced into the applied econometric analysis of firm research-and-development activity by Scherer,[17] is important when examining interfirm differences in research-and-development activity. While our sample of firms is drawn from the food and kindred-products industries (SIC 20), it is nonetheless a heterogeneous collection of firms both with regard to products and production technologies. Across these industries the value of research-and-development activity varies widely. In the corn wet-milling industry, for example, there have been a number of important discoveries in recent years, and firm R & D is an important competitive activity. In the baking industry, on the other hand, firm research does not appear to be a major competitive strategy.

The technology underlying the firm's production function accounts for these interindustry differences in the importance of R & D. Within some industries, science offers many opportunities for advances; within others, the likelihood of major product or production advances is small. This does not, of course, preclude advances originating outside the industry. In the baking industry, for example, few resources (relative to other industries) are devoted to research and development, and inventions utilized by the industry will most likely be developed by the industries that supply machinery to the baking industry. Thus, the nature of the technology underlying the firm's production function induces an ordering of "technological opportunity." For given values of all structural variables, the expected level of firm research-and-development activity will depend on the industry in which the firm operates. Of course, few firms are so specialized their "technolgical opportunities" correspond directly to the technologies underlying the production function in their primary industry. Fortunately, in the food industries many firms are still quite highly specialized, and when firms do diversify, they often enter into industries with very similar "technological opportunities."

PERCENT FOREIGN AND PERCENT NON-FOOD

The proportion of firms' sales resulting from activities other than food manufacturing was used as a variable by Imel, *et al.,* who argued:

> Since some food companies have diversified into other than food industries, however, particularly into chemicals, it was deemed neces-

sary to include a variable to account for the greater opportunities that are likely to be open to such companies.[18]

This line of reasoning is consistent with the discussion of industry technological opportunity. There is one significant difference, however, since the "percent nonfood" variable implicitly assumes that all nonfood industries have the same technolgical opportunities. We will correct for variations of technolgical opportunities at the 2-digit level by utilizing an index of technological opportunity.[19]

Firm inventive activity has been hypothesized as one of the factors that explains direct foreign investment by United States firms. Firms invest in foreign subsidiaries to market new products that were invented and successfully marketed in the United States.[20] Thus, we hypothesize that the larger the role of foreign subsidiaries in the sales of a firm, the less the firm's R & D will be since it does not engage in significant inventive activity for the foreign share of its sales.

CONCLUSION

This chapter has examined a variety of hypotheses relating firm- and market-structure variables to the costs, inputs, and outputs of firm research-and-development activity. Fisher and Temin in their article "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?" raise some serious questions concerning the relationship between the theory and empirical work in R & D studies. They show that increasing average R & D productivity with firm size, or laboratory size (or both), is neither necessary nor sufficient to show that the elasticity of firm research-and-development inputs or outputs with respect to firm size exceeds one. While not explicity stated, these results appear to apply to the structural variables of market power and diversification as well. They conclude:

> Our model contains the features which seem to lie behind the intuition that the effects of the two types of increasing returns in R & D are to make research inputs and research outputs go up more than proportionally with firm size. We show that such intuition is in fact incorrect and that there is thus no *prima facie* reason for believing that such conclusions follow. This is not to deny that they might indeed follow in a better or more elaborate model of the innovative process as envisaged by Schumpeter, but that possibility must now be considered mere speculation in the absence of proof.[21]

Based on this result, the industrial-organization theory discussed in this chapter must be considered more suggestive than conclusive. Yet, the present study is an empirical one. Its purpose is to determine if a statistically significant relationship exists between structural variables and firm research and development. If the history of science is any guide, observed empirical relationships will be followed by improvements in theory.

FOOTNOTES

[1] F.M. Scherer, *Industrial Market Structure and Economic Performance,* (Chicago: Rand McNally, 1980), p. 411.

[2] Scherer, *ibid,* pp. 413-414.

[3] The variance declines as *firm size* increases since these assumptions imply that the number of R & D projects increases with firm size.

[4] Scherer, *op. cit.,* pp. 415-418.

[5] Numerous examples of inventions of this type are included in Jewkes, *et. al., The Sources of Invention.* The invention and subsequent development of Kodachrome (pp. 266-268) and the catalytic cracking of petroleum (pp. 235-237) are two prominent inventions that aptly fit this mold.

[6] Willard F. Mueller, "The Origins of the Basic Inventions Underlying Du Pont's Major Product and Process Innovations, 1920 to 1950," in the National Bureau of Economic Research Conference report *The Rate and Direction of Inventive Activity* (Princeton: Princeton University Press, 1962), pp. 232-246.

[7] The density function of Pareto distribution is given by:

$$f(x) = \frac{a x_o^a}{x^{a+1}} \qquad [x_o < x < \infty] \qquad x_o > 0 \quad a > 0$$

density function declines monotonically as x ranges from x_o to ∞.

[8] F.M. Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions," *American Economic Review,* December 1965, p. 1098.

[9] W.F. Mueller and R.T. Rogers, "The Role of Advertising in changing Concentration in Manufacturing Industries," *Review of Economics and Statistics* February 1980, pp. 90-91.

[10] Scherer (1970), *op. cit.,* pp. 416-418.

[11] *Ibid,* p. 414.

[12] Joseph A. Schumpeter, *Capitalism, Socialism, and Democracy,* (Third ed., New York: Harper, 1950), p. 106.

[13] *Ibid.,* p. 91.

[14] The following discussion is based on: Schumpeter, *op. cit.,* pp. 87-90.

[15] R. Nelson, "The Simple Economics of Basic Research," *Journal of Political Economy,* June 1959, p. 320.

[16] See Table 1.5. In 1975, 8 percent of research in the food and kindred products area was in basic-science research.

[17] Scherer (1965), *op. cit.,* p. 1100.

[18] Blake Imel, Michael R. Behr, and Peter G. Helmberger, *Market Structure and Performance* (Lexington, Massachusetts: Lexington, 1972), p. 67.

[19] The percent nonfood variable was constructed by multiplying the percent of firms sales outside the food industries by a weighted average of the technological opportunities in the nonfood industries into which firms diversified. The indexes technological opportunities, at the two-digit level, are the intercept terms from Scherer's (1965) regression analysis (p. 1101).

[20] W. Bruber, D. Mehta and R. Vernon, "The R & D Factor in International Trade and International Investment of United States Industries," *Journal of Political Economy,*February 1967, pp. 20-378. For a conflicting view see Edwin Mansfield, Anthony Romeo, and Samuel Wagner, "Foreign Trade and U.S. Research and Development," *Review of Economics and Statistics,* February 1979, pp. 49-57.

[21]F.M. Fisher and P. Temin, "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?", *Journal of Political Economy,* January/February 1973, p. 61.