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In a recent article in this *Journal*, Edwin Mansfield presented the innovation histories of the iron and steel, petroleum refining, and bituminous coal industries and ingeniously interpreted the data using a series of statistical models.[2] Among the questions that he investigated is the following: What factors influence the proportion of innovations that will be introduced by the four largest firms in an industry? The present analysis raises a somewhat different but related question: What factors influence the relative proportion of innovations (that is, proportion of innovations in relation to market share) that will be introduced by the four largest firms? Formulating the question in this way permits us to focus directly on the issue of how monopoly power affects the relative contributions of these largest firms.

I

Since our preliminary results will be derived from Mansfield's Table 2, we reproduce below the relevant portions of that Table.

Before attempting to explain these data, we might examine first those factors which, on *a priori* grounds, are believed to affect the innovative performance of the largest firms in an industry. There would appear to be at least three. First, the largest firms may

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Table 1

PERCENT OF INNOVATIONS AND CAPACITY ACCOUNTED FOR BY LARGEST FOUR FIRMS

Item	Weighted Percent of Industry Total		
	Steel	Petroleum	Coal
1919-38			
Process innovations	39	34	
Product innovations	20	60	
All innovations: P	30	47	27
Capacity (or output): C	62	33	11
Relative Performance: R = P/C	.48	1.42	2.46
1939-58			
Process innovations	58	58	
Product innovations	27	40	
All innovations: P	43	49	30
Capacity (or output): C	63	39	13
Relative Performance: R = P/C	.68	1.26	2.31

Source: Mansfield, op. cit., p. 561, Table 2 possess scale and financing advantages relative to their smaller rivals. Thus, if we designate the proportion of innovations introduced by the four largest firms in the ith industry by P_i and the market share (or relative capacity) of these firms by C_i, and if there were no other influences affecting innovative performance, we should observe that $P_i/C_i > 1.0$, for all i. That is, due to relative size advantages, the four largest firms in every industry should account for more than their pro rata share of innovations.

However, there may be other factors that influence the participation rate of these four largest firms. Thus the rewards for innovations that the largest firms have access to may differ between industries, and this could produce some interindustry differences in the ratio P_i/C_i. In addition, the pressure to innovate that the largest firms experience may differ between industries, and this could also affect the ratio.

Although an *a priori* case can be made for the proposition that a monopolistic market structure enhances both the rewards and pressures for the largest firms to innovate, a case can also be made for the opposite. Consider the reinforcement argument first. Here it is claimed that the rewards associated with innovation increase as market control increases.[3] Appropriability is presumably greater among the largest firms in highly concentrated, oligopolistic industries. Thus the relative rate of innovation of large firms might be expected to increase as monopoly power increases. Moreover, if successful innovation by one of these large firms serves either to induce or incite innovation among its principal rivals, a pervasive pressure to innovate may prevail among the largest firms in a highly concentrated industry.[4] Contrast this with a competitive industry, where the largest firms possess neither market control nor intimate interdependencies with their rivals. The same types of incentives and pressures among the largest firms may here be lacking. This argument therefore suggests that the ratio P_i/C_i should vary directly with the degree of monopoly power -- everywhere exceeding unity due to scale advantages, but becoming largest where monopoly control is greatest.

This position has not gone unchallenged. The alternative, or competitive, hypothesis is that size advantages are quickly exhausted and that increasing monopoly power impairs the relative innovation record of large firms. Thus, in the short run, monopoly advantages may permit the largest firms to neglect the behavior of their rivals, while over the long run the recognized degree of interdependence among the principal rivals may lead to calculated efforts to restrain innovation and thereby preserve stable interfirm relations. Lacking compulsion to innovate in the short run and anxious to moderate competition in the long run, the relative innovative performance of the largest firms may decline as monopoly power increases. This is contrasted with circumstances in a competitive industry where differential advantages may be available only to the extent that a firm is a successful innovator. Hence, the incentives to innovate are held to be particularly keen where competitive conditions prevail.[5] Moreover, powerful pressures to offset successful innovation may be expected where insularity is missing.[6] Although these incentives and pressures presumably face all of the firms in a competitive industry, they may be especially strong among the largest firms which lack the local advantages of their smaller rivals. According to this hypothesis, therefore, the ratio P_i/C_i should vary inversely with the degree of monopoly power.

Actually, there is no need wholly to accept or reject either of these two positions. Parts of both hypotheses are probably correct. The real question is: What is the net effect of these several influences? Clearly this is an empirical rather than a theoretical issue.

Letting $R_i = P_i/C_i$ be the relative innovative performance of the four largest firms in the ith industry, S_i be the scale advantages that these firms have access to, and M_i be the degree of monopoly power, we have

$$(1) \qquad R_i = f(S_i, M_i, \ldots)$$

$$f_{S_i} > 0$$

$$f_{M_i} > 0 \text{ (increasing returns hypothesis)}$$

$$f_{M_i} < 0 \text{ (decreasing returns hypothesis)}$$

II

Defining the concentration ratio to be the market share of the four largest firms (C), treating this as an approximate measure of the degree of monopoly power,[7] and relegating other factors that influence innovative performance to a random error term that is assumed to be uncorrelated with the concentration ratio, we can test these alternative hypotheses with the following model:

(2) $$R_{it} = \alpha_0 + \alpha_1 C_{it} + U_{it} \quad ,$$

where R_{it} is the ratio of P to C in the ith industry in the tth period, C_{it} is the corresponding concentration ratio, and U_{it} is a random error term. Alternatively we might test the relation:

(3) $$R_{it} = \beta_0 C_{it}^{\beta_1} V_{it} \quad ,$$

where R_{it} and C_{it} are as defined above and V_{it} is a random error term.[8] Positive values for the parameters associated with the concentration ratio (α_1 and β_1 respectively) indicate that the relative advantage of the four largest firms increases as monopoly power increases, whereas negative values for these parameters indicate decreasing returns.

Using the data in Table 1, we obtain the following least squares estimates of the relations:

(4) $$R_{it} = 2.73 - \underset{(.0027)}{.0354}\ C_{it} \quad ,$$

(5) $$\ln R_{it} = 2.77 - \underset{(.145)}{.809}\ \ln C_{it} \quad ,$$

where the figures in parentheses are standard errors and ln denotes the natural logarithm. The coefficient of correlation for equation (4), adjusted for degrees of freedom, is .985, while that for equation (5) is .926. The fit of the model to the data is surprising. The signs and significance of the estimates of α_1 and β_1 clearly suggest that the relative share of innovations contributed by the largest firms in an industry decreases as monopoly power, as measured by the concentration ratio, increases. Indeed, based on the linear model, the four largest firms in an industry appear to contribute less than their proportionate share of innovations when the concentration ratio exceeds 50 per cent (at which value the predicted value of R_{it} is 1.0), and more than their proportionate share when the concentration ratio is less than 50 per cent. Using the second model, which is linear in the logarithms, the concentration ratio would have to fall to 30 per cent before the four largest firms would be contributing innovations in proportion to their capacity.

Probably more interesting than these relative share effects is the question of how the absolute innovative performance of an industry is affected by concentration. Letting T_i be the value of all innovations in industry i, L_i be the value of those accounted for by the largest four firms, and Q_i the value of those introduced by their smaller rivals, we have

$$(6) \qquad T_i \equiv L_i + Q_i \quad ,$$

where $L_i/T_i \equiv P_i$, and $P_i \equiv R_i\ C_i$. Behavioral content can be provided to these relations by substituting our emperical estimates of R_i in terms of C_i, and by specifying how Q_i is affected by market structure. Thus we hypothesize that

$$(7) \qquad Q_i = [(100 - C_i)\ g\ (C_i)]\ h\ (i) \quad ,$$

where $100 - C_i$ is the market share of the smaller firms, $g(C_i)$ reflects the influence of market structure on the innovative performance of these smaller firms, and h(i) is an index of the potential innovations available to firms in the ith industry.

Specifying $g(C_i)$ is the critical problem. If we assume that the innovative performance of these smaller firms is stimulated by concentration then $g'(C_i) > 0$, whereas $g'(C_i) < 0$ if we assume the contrary. Lacking a basis for preferring either of these alternatives, we arbitrarily assign a "neutral" value to $g(C_i)$ of unity.[9] Under this assumption we have

$$(8) \qquad T_i = 100 \frac{100 - C_i}{100 - R_i C_i} h(i) \quad .$$

Substituting our empirical estimates of R_i and maximizing this expression with respect to C_i, we obtain an "optimal" concentration of 30 using the linear model, and 5 using the log-linear model. Although we are disinclined to attach policy significance to these particular results, presumably field study investigations could be designed to provide the necessary information on the relation $g(C_i)$. Combined with additional empirical data on innovative performance of the sort collected by Mansfield, an estimate of the (so far elusive) overall effect of market structure on innovation could be obtained by an application of this approach.

A number of objections can be rasied to the preceding analysis. For one thing the sample may not be representative. For another, the observations may not be independent. In addition, the measurements may be biased in favor of the decreasing returns hypothesis. We will consider each of these objections in order.

That the sample may be non-representative is always a possibility in small sample work. This is true here, and the most that we can claim for these results at this time is that they are suggestive. The possibility that the observations are not independent also deserves consideration. Thus it might be objected that while we have used six observations in estimating the parameters, in fact we have only three industries and the observations are divided into two periods (1919-38 and 1939-58) arbitrarily. Although there is something to be said for this view, there is also a case for treating the data as though all of the observations were independent. Each of the time periods covers a twenty-year history and the conditions that dictated research decisions in the inter-war period could easily be changed by those that prevailed during World War II and since. Hence the observations could be substantially independent. Since both positions are conjectural, and since dividing the observations allows us to examine the proposition that the relative performance of the largest firms has improved recently,[10] we estimate the parameters in equations (2) and (3) for each of the periods taken separately. The results are shown in Table 2.

We find that whether the periods are treated separately or together, the results are substantially unchanged. The influence of concentration on the relative performance of the largest four firms is negative and quite stable. Moreover both estimates of α_1 are significant at nearly a 5 per cent level, despite the fact that they are based on only one degree of freedom, and one of the estimates of β_1 is significant at the 10 per cent level. Thus not only do these results support those obtained when all the observations were pooled, but they contradict the proposition that the relative performance of the largest firms has substantially improved recently.

Table 2

RELATION OF CONCENTRATION TO INNOVATION: 1919-38 and 1939-58 RUN SEPARATELY

	Linear Model			Loglinear Model		
Period	α_0	α_1	$\bar{R}$	$\ln\beta_0$	β_1	$\bar{R}$
1919-38	2.63	-.0333 (.0064)	.992	3.14	-.889 (.423)	.886
1939-58	2.67	-.0326 (.0048)	.994	2.69	-.733 (.200)	.948

The possibility that the measurements are biased in favor of the decreasing returns hypothesis has yet to be examined. Two possible biases exist. First, suppose that most of the firms in industries with high concentration ratios tend generally to be of sufficient size to benefit from the types of innovations reported by Mansfield, while most of the firms in industries with very low concentration ratios tend generally to be too small to innovate. That is, if we divide the firms in each industry into potential innovators and others, a negligible fraction of industry capacity may be accounted for by the firms too small to innovate in the high concentration industries, while this proportion may be substantial in the low concentration industries. Assume that such conditions prevail. Assume also that within the group of firms designated as potential innovators, the largest firms account for innovations exactly in proportion to their relative capacities. Under such circumstances, the tests that we have performed will be biased in favor of the competitive hypothesis.[11] To check this possibility we examined the data on asset size in the steel and petroleum industries (which are the only ones for which the asset breakdown on potential innovators are available) as reported by Mansfield in his Table 3, and compared the total assets accounted for by the group of firms designated as potential innovators to the assets of all firms. The analysis reveals that there is a very weak tendency for the above described effect to operate, but hardly enough to change significantly the regression results.[12]

It might be argued that our deflating procedure (dividing P_i by C_i) constitutes a second source of bias. Thus suppose that we have two stochastically independent random variables, X and D, and that values of X and D drawn from their respective distributions are randomly paired. Should we run a regression of X on D we would expect to obtain a zero correlation. If, however, we divide X by D and then correlate X/D with D, we would find that large values of D tend to produce small values of the ratio X/D, and small values of D would be associated with large values of X/D. Hence a negative correlation would obtain when in fact X and D are completely independent. More precisely, whereas the covariance of X and D in these circumstances is zero, the covariance of X/D and D is negative.[13] But the neutral hypothesis is not that P_i and C_i are independent, but that the expected value of P_i is C_i (or perhaps kC_i, where $k > 1$, reflecting scale advantages of the largest firms). The reinforcement hypothesis is that P_i increases with C_i and at an increasing rate, and the competitive hypothesis is that P_i increases with C_i but at a decreasing rate. In ratio terms, P_i/C_i should be uncorrelated with C_i under the neutral hypothesis, positively correlated under the reinforcement hypothesis, and negatively correlated under the competitive hypothesis.

Thus the random counterpart for the "neutral" hypothesis is not that X and D are stochastically independent, but that the expected value of X is D (or kD). Under these circumstances, high and low values of X will tend to be associated respectively with high and low values of D. Hence the ratio X/D will not be negatively correlated with D. Instead a zero correlation would be expected. Hence, the claim that our deflating procedure biases the results in favor of the competitive hypothesis rests on a faulty specification of neutrality and, indeed, is incorrect.

III

The paucity of the data constitutes a serious objection to the analysis. It is worth pointing out, however, that large amounts of general purpose data, such as are reported routinely in government and trade publications, are unlikely to get at the fundamental issues in the innovation-market structure dispute, while small amounts of carefully collected special purpose data would appear to promise uncommonly large returns.

Whether the results obtained from the present analysis would be supported by such additional data is, of course, uncertain; at best we would treat the parameter estimates reported here as merely suggestive. The procedures employed, however, indicate one way in which special purpose data of the sort collected by Mansfield can be made to shed insights on these vital matters.

FOOTNOTES

1. Most of the work was done under a grant from the Ford Foundation administered by the Center for Research in Management Science, University of California, Berkeley. The helpful comments of RAND colleagues R. R. Nelson and Almarin Phillips were appreciated. Any errors are, of course, my own.

2. Edwin Mansfield, "Size of Firm, Market Structure, and Innovation," Journal of Political Economy, December, 1963.

3. See J. A. Schumpeter, Capitalism, Socialism and Democracy (New York: Harper and Bros., 1947), esp. Ch. 8. Kaysen and Turner have summarized his argument as follows: "The idea that monopoly in some degree might be an important prerequisite of a high rate of progressiveness was first formulated by Schumpeter.... His central notion was that some degree of market power provided both the finance and the 'breathing space' which made possible the risky investments in innovation, and also provided the rewards...which were necessary to stimulate others to innovate." Carl Kaysen and Donald F. Turner, Antitrust Policy (Cambridge: Harvard University Press, 1959), p. 83. This position is also developed by Henry H. Villard, "Competition, Oligopoly, and Research," Journal of Political Economy, December 1958, pp. 491-92.

4. Villard, op. cit., p. 493 argues that these pressures have frequently been unusually severe in industries where firms are big and few. However, he is also concerned lest a quest for the "quiet life" evolve in these circumstances.

5. Kaysen and Turner, op. cit., p. 85.

6. Nutter argues that "the fall in costs to the innovating firm must be large relative to costs in other firms and to the extent of the market before that firm can gain significant control over the market. Otherwise it will simply earn economic rent." G. Warren Nutter, "Monopoly, Bigness, and Progress," Journal of Political Economy, December, 1956, p. 522. If, as Nutter suggests, the advantages show up mainly in profits rather than prices, the pressures indicated above may fail to materialize.

7. That the concentration ratio is an imperfect measure of the degree of monopoly power is well known. Thus an adjustment for differences in product and regional characteristics is frequently warranted, although for the industries included in the present sample such a corrected measure would yield an ordering roughly the same as the unadjusted measure used here. Also, ordering the industries according to relative ease of entry would yield a measure of monopoly power identical in ordering to that used here. For an earlier analysis of the relation of technological progress to the degree of monopoly that also uses the concentration ratio as the measure of monopoly power, see G. J. Stigler, "Industrial Organization Economic Progress," in The State of the Social Sciences, (L. D. White, ed.), Chicago: University of Chicago Press, 1956. More recently, D. Hamberg has

also used the concentration ratio for this purpose in this "Size of Firm, Oligopoly, and Research: The Evidence," Canadian Journal of Economics and Political Science, February,1964, pp. 74-75.

8. If we formulate the test in terms of proportions of innovations accounted for by the largest four firms instead of relative proportions, as above, the respective models would be

$$(2') \qquad P_{it} = \alpha_0 C_{it} + \alpha_1 C_{it}^2 + U_{it}' \quad ,$$

$$(3') \qquad P_{it} = \beta_0 C_{it}^{1+\beta 1} V_{it}$$

A more homoscedastic error term obtains by dividing through by C_i and testing the relations shown in the text.

9. Any constant will do. All that we require is that $g'(C_i) = 0$ to obtain a neutral effect. This implies that the smaller firms in an industry introduce innovations according to some regular process that is not affected in any significant way by market structure.

10. Stigler finds this attitude characteristic of certain recent opinions, ibid., p. 277.

11. To see this, let C_4 be the capacity of the largest four firms, C_P be the capacity of all firms of potential size to innovate, C_T be total industry capacity, P_4 be the proportion of innovations introduced by the four largest firms, and R_4 be given by $R_4 \equiv \frac{P_4}{C_4/C_T}$. By hypothesis, $P_4 = C_4/C_P$. Thus $R_4 = \frac{C_T}{C_P}$. If among the more highly concentrated industries $C_P \cong C_T$, while among the unconcentrated industries $C_P < C_T$, the measured R_4 will favor the decreasing returns hypothesis.

12. Taking the ratio of total capacity to capacity accounted for by all firms of potential size, we obtain the following results:

	Steel	Petroleum
1919-38		
Process	1.16	1.15
Product	1.18	1.24
1939-58		
Process	1.06	1.08
Product	1.05	1.18

In 1919-38 the corrections to be applied are virtually identical, and hence can be neglected. In the period 1939-58, the difference in the corrections is in the direction that we hypothesized, but is hardly enough to affect the results. Since the data are not available with which to make the corresponding corrections for bituminous coal, we leave our previous results unchanged.

13. For example, if X and D are stochastically independent random variables each uniformly distributed over the interval .1 to .6 (which is the approximate range of C_i for the observations in question), then, by an appropriate transformation of variables, it can be shown that

$$\rho_{X/D,D} \equiv \frac{\text{Covariance of } X/D \text{ and } D}{\sigma_{X/D}\,\sigma_D} = -.66 \quad ,$$

where $\rho_{X/D,D}$ is the correlation coefficient and $\sigma_{X/D}$ and σ_D are the square roots of the respective variances. Moreover, if the relation between X/D and D is assumed to be linear, the following regression function is obtained.

$$E(X/D|D) = 2.75 - .043\ D.$$

Comparing this with the regression results in equation (4) (where $R_{it} = 2.73 - \underset{(.003)}{.035}\, C_{it}$, $\hat{\rho} = -.99$), we find that the random model provides a generally close fit to the estimates actually obtained. Indeed, although our correlation coefficient of -.99 is significantly different from -.66 at the .05 level, and hence our results are probably not simply due to chance, we also note that the estimated value of the parameter associated with the concentration ratio is significantly smaller than the expected value of the corresponding parameter in the random model. Hence, it might be argued, our regression results do not support the competitive hypothesis as previously indicated, but actually deviate from the random model in favor of the reinforcement hypothesis.