R&D Appropriability, Opportunity, and Market Structure: New Evidence on Some Schumpeterian Hypotheses

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One of the largest bodies of literature in the field of industrial organization is devoted to the interpretation and testing of several hypotheses advanced by Joseph Schumpeter (1950) concerning innovation and industrial market structure. One set of hypotheses focuses on the role of firm size as a determinant of *R&D* spending and the rate of technological advance. Another set focuses on the effect of market concentration on *R&D* and technological advance. In this paper, we reexamine the latter set of hypotheses at the industry level, using new data on *R&D* appropriability and technological opportunity collected by Levin et al. (1984) in a survey of *R&D* executives in 130 industries.

I. Motivation

Despite the voluminous literature, theory yields ambiguous predictions about the effects of product market concentration on *R&D* spending and on innovative performance. For example, it is often argued that firms in concentrated markets can more easily appropriate the returns from their *R&D* investments. On the other hand, it is argued that gains from innovation at the margin are larger for competitive firms than for monopolists, but this argument neglects systematic differences in the probability of imitation or in costs of adjustment. Schumpeter himself emphasized that concentration reduces market uncertainty and provides the cash flow required to engage in costly and risky *R&D* on an efficient scale. Others have argued that insulation from competitive pressures breeds bureaucratic inertia and discourages innovation. Still others have used a combination of arguments to rationalize the "inverted-U" relationship frequently observed in the empirical literature, whereby innovative effort or innovative output first increases with concentration and then decreases.

One reason for skepticism about the existence of a direct effect of concentration on innovation is that theoretical arguments justifying such an effect tend to appeal to more fundamental technological or institutional conditions. The empirical literature lends some support to the view that innovation depends on more fundamental conditions. F. M. Scherer (1967) found that the statistical significance of concentration was substantially diminished when a vector of dummy variables categorizing industries by the nature of their technology (chemical, electrical, mechanical, and traditional) was added to the regression. Scherer and others have interpreted these categorical variables as proxies for technological opportunity. Technology classes differ in more than opportunities for technical advance, however; they also differ in the inherent ease of imitation and in the strength of patent protection. The technology class variables used in the literature are thus best interpreted as proxies for both opportunity and appropriability.

Concentration may also proxy for a broader range of industry-specific effects, as suggested in John Scott's (1984) study of *R&D* spending at the business unit level. Using Federal Trade Commission (FTC) data, Scott first replicated the standard inverted-U result, but when fixed effects were added for two-digit industries, as well as for

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companies, the t-statistics on the concentration terms dropped by an order of magnitude.

These results suggest that industrial concentration may have no independent significance as a determinant of innovative effort or innovative output. To explore this issue, we attempt to control for systematic interindustry differences in appropriability and opportunity, using data from the Levin et al. survey. We also take account of the possible effects of *R&D* and innovation on market concentration, recognizing that Schumpeter's insights about the role of innovation in determining market structure may be more fundamental than his widely tested hypotheses concerning the feedback from market structure to innovation incentives.

We estimate equations for both *R&D* and innovative output. In the best of worlds, these equations would be embedded in a structural model and derived rigorously. This is the approach taken in related work by Levin and Peter Reiss (1984). We believe nonetheless that there is ample justification for the kind of "pre-theoretical" statistical investigation reported here. Theorists often begin with the "stylized facts." We offer this exploratory data analysis with the hope of providing to other researchers a more accurate assessment of the stylized facts.

II. Empirical Results

We take as our unit of observation the line of business (LB) as defined by the FTC; some LBs correspond to four-digit SIC industries and others correspond to groups of four-digit or to a single three-digit industry. As dependent variables, we use the ratio of company-financed *R&D* expenditures to sales from the 1976 Line of Business data and a measure of innovation derived from responses to two questions in the Levin et al. survey. Respondents were asked to score on a seven-point scale the rates at which new products and new processes were introduced into their LBs during the 1970's. We measure innovation in each LB by summing the mean scores on these two questions. Concentration ratios are taken from the 1972 Census of Manufacturers, and aggregated to the LB level when necessary. Since intertemporal changes in concentration and in *R&D* intensity occur slowly, we test each of our reported specifications for indications of simultaneity.

Consistent with the conventional wisdom, *OLS* and *2SLS* regressions of *R&D* intensity on concentration, its square, and a constant term provide support for the inverted-U hypothesis. Since independence of the concentration variables and the disturbance term is decisively rejected, we report the *2SLS* version (with asymptotic standard errors in parentheses):

$$(1)\quad RD/S = \underset{(1.402)}{1.810} + \underset{(0.067)}{0.166\,C4} - \underset{(0.068)}{0.159(C4SQ \times 100)}.$$

The coefficients on $C4$ and $C4SQ$ are both significant at the .01 level (one-tailed tests). Consistent with the previous literature, in which innovative effort typically reaches a maximum at levels of $C4$ between 50 and 60, our results indicate that *R&D* intensity is maximized at a $C4$ of 52.

We get similar results by regressing our innovation measure on concentration. Here, however, we report *OLS* estimates, since we cannot reject the hypothesis that concentration and its square are independent of the disturbance term:

$$(2)\quad INNOV = \underset{(0.790)}{6.013} + \underset{(0.036)}{0.089\,C4} - \underset{(0.036)}{0.082(C4SQ \times 100)}.$$

The coefficients are again significant at the .01 level, and the rate of innovation reaches a maximum at a $C4$ of 54.

Controlling for two-digit industry fixed effects, we find that the coefficients of the concentration terms are somewhat reduced in the *R&D* equation, but both remain significant at the .10 level and *R&D* reaches a maximum at a $C4$ of 54. Controlling for fixed effects has virtually no impact on the innovation rate equation. The coefficients on the concentration terms are essentially unchanged, and they remain significant at the .01 level. The rate of innovation is maximized at a *C4* of 58.

To examine whether the effect of concentration on innovative effort and output is more seriously attenuated when direct measures of technological opportunity and appropriability are included in the regressions, we constructed several variables from the Levin et al. survey data. Analysis of the survey data is still in progress, and undoubtedly the quality of the results reported here can be improved once the statistical properties of the survey responses are more fully understood.

Our variables are intended to capture three dimensions of technological opportunity: closeness to science, external sources of technical knowledge, and industry maturity. To measure closeness to science, we used survey responses concerning the relevance of various basic and applied sciences to the technology of each industry. *SCIENCEBASE* was defined as the maximum score received by any one of the eleven fields of science listed on the questionnaire. We also took account of the contributions to an industry's technical knowledge from four external sources: upstream suppliers of raw materials and equipment (*MATERIALTECH* and *EQUIPTECH*, respectively), downstream users of the industry's products (*USERTECH*), and government agencies and research laboratories (*GOVTECH*). Each of these opportunity variables is measured on a seven-point scale. In light of the widely held view that technological opportunity may vary systematically as an industry matures, we also included a variable intended to capture the relative immaturity of an industry's technology. This was operationalized as the percentage of an industry's property, plant, and equipment that was installed within the five years preceding 1976 (*NEWPLANT*), as reported to the FTC's Line of Business Program.

We used two variables to represent appropriability conditions. The Levin et al. survey asked respondents to characterize (on a seven-point scale) the effectiveness of six mechanisms used by firms to capture and protect the returns from new processes and new products resulting from *R&D* efforts. The listed mechanisms were patents to prevent duplication, patents to secure royalty income, secrecy, lead time, moving down the learning curve, and complementary sales and service efforts. We limit ourselves here to an attempt to discern whether our sample industries had any effective mechanism of appropriation. We therefore operationalize *APPROPRIABILITY* as the maximum score received by any one of the six mechanisms for either process or product *R&D*.

The survey also asked industries to report on the range of imitation costs and time lags for major and minor, process and product, and patented and unpatented innovations. These measures tend to be highly correlated with one another, though they are not highly correlated with *APPROPRIABILITY*. We use here the average time (in months) required to duplicate a patented, major product innovation (*IMLAG*).

Our principal interest in this paper is the robustness of the results that innovative effort and output depend on concentration. In the absence of an explicit structural model, however, prior expectations about the signs of the opportunity and appropriability variables are in some cases ambiguous. Opportunity, as measured by closeness to science and the strength of other external influences on technology, should have a positive effect on innovative output, but to the extent that the efforts of upstream suppliers, downstream users, and the government substitute for an industry's own *R&D* effort, these variables may have a negative sign in the *R&D* equation. Appropriability may also have ambiguous effects on *R&D* incentives, as recent theoretical work has emphasized. Some effective means of appropriating returns is surely required to elicit *R&D* effort. Spillovers among competitors, however, are ambiguous in their effects. They create a disincentive to *R&D* investment by dissipating the innovator's rents, but they also enhance the productivity of *R&D* by strengthening the industry's knowledge base (see Michael Spence, 1984). Thus, *APPROPRIABILITY*, which measures the extent to which an industry has at least one effective means of appropriation,

TABLE 1—DETERMINANTS OF *R&D* INTENSITY (*2SLS* ESTIMATES)

	Regression Coefficients (1)	(2)
Intercept	−4.650[c]	[a]
	(2.324)	
C4	0.022	−0.005
	(0.082)	(0.073)
C4SQ ×100	−0.013	0.002
	(0.082)	(0.072)
NEWPLANT	0.048[b]	0.025[b]
	(0.015)	(0.014)
SCIENCEBASE	0.469[b]	0.490[b]
	(0.215)	(0.202)
MATERIALTECH	−0.043	−0.037
	(0.163)	(0.154)
EQUIPTECH	−0.368	0.164
	(0.190)	(0.185)
USERTECH	0.365[c]	0.029
	(0.150)	(0.152)
GOVTECH	0.304[c]	0.282[c]
	(0.129)	(0.139)
APPROPRIABILITY	0.069	0.196
	(0.258)	(0.243)
IMLAG	0.052	0.100
	(0.073)	(0.068)
Chi-Square Tests (*D.F.*):		
All survey vars. (7)	3.713[d]	2.487[d]
Opportunity vars. (5)	4.820[d]	2.917[d]
Appropr. vars. (2)	0.287	1.395
Industry dummies (13)		3.864[d]

Note: Asymptotic standard errors are shown in parentheses.
[a]Separate intercepts for 14 industry groups.
[b]Significant at .05 level (one-tailed t-test).
[c]Significant at .05 level (two-tailed t-test).
[d]Significant at .05 level (*Chi*-square test).

TABLE 2—DETERMINANTS OF THE RATE OF INNOVATION (*OLS* ESTIMATES)

	Regression Coefficients (1)	(2)
Intercept	−4.893	[a]
	(2.558)	
C4	0.055	0.048
	(0.037)	(0.038)
C4SQ ×100	−0.039	−0.036
	(0.038)	(0.038)
NEWPLANT	0.042[b]	0.017
	(0.018)	(0.019)
SCIENCEBASE	0.371	0.439[b]
	(0.240)	(0.253)
MATERIALTECH	0.388[b]	0.294
	(0.184)	(0.191)
EQUIPTECH	0.246	0.472[b]
	(0.204)	(0.234)
USERTECH	0.277	0.035
	(0.172)	(0.195)
GOVTECH	0.048	0.051
	(0.148)	(0.178)
APPROPRIABILITY	0.564[b]	0.745[b]
	(0.266)	(0.279)
IMLAG	−0.035	−0.025
	(0.082)	(0.085)
F-Tests (*D.F.*):[c]		
All survey vars. (7)	2.797[d]	2.682[d]
Opportunity vars. (5)	3.288[d]	2.633[d]
Appropr. vars. (2)	2.307	3.573[d]
Industry dummies (13)		1.640

Note: Standard errors are shown in parentheses.
[a]Separate intercepts for 14 industry groups.
[b]Significant at .05 level (one-tailed t-test).
[c]Numerator D.F. in parentheses; denominator *D.F.* is 116 for col. (1) and 103 for col. (2).
[d]Significant at .05 level (*F*-test).

should have a positive effect on both innovative effort and output. On the other hand, a long imitation lag, which inhibits spillovers, may encourage innovative effort by reducing the disincentive effect, but it may also reduce innovative output, by reducing the productivity of *R&D*.

Table 1 displays estimates of the *R&D* intensity equation, alternately excluding and including two-digit industry fixed effects. We again report *2SLS* results, because the hypothesis of independence between the concentration terms and the disturbance is rejected by Wu tests. We also found no evidence of heteroskedasticity, despite the fact that the number of responses to the Levin et al. survey varied across industries.

Comparing Table 1 with (1) in the above text, the coefficients and t-statistics on the concentration terms fall by an order of magnitude. There are no anomalous signs; the survey variables as a whole and the opportunity measures in particular are highly significant. Specifically, *R&D* spending appears to be encouraged in youthful industries where a strong science base is present and where the government makes substantial contributions to technological knowledge. The continued statistical significance of these variables when fixed industry effects are taken into account suggests that we may have isolated some relevant dimensions of technological opportunity.

Table 2 presents *OLS* estimates of the innovation equation. The *2SLS* estimates were substantively identical, and we found no evidence of simultaneity. Once again, the concentration terms become statistically insignificant at the .05 level once the survey variables are added to the equation, although the linear term is significant at the .10 level. All survey variables have the predicted sign, and they are jointly significant at the .05 level. The two-digit industry effects are jointly insignificant, but their inclusion strengthens the performance of several survey variables: *SCIENCEBASE*, *EQUIPTECH*, and *APPROPRIABILITY*. The signs of the coefficients on *APPROPRIABILITY* and *IMLAG* conform to the expectations discussed above.

III. Conclusions

In the spirit of "creative destruction," we hope that our findings will at last move the empirical literature beyond the oversimplified propositions that industrial concentration promotes innovative effort and innovative output. To explain interindustry variation in *R&D* incentives and the productivity of innovative effort, we must look to underlying differences in technological opportunities and appropriability conditions. In this paper, we have made only illustrative use of the Levin et al. data. These new data, and a burgeoning theoretical literature on *R&D* competition in the presence of imperfect appropriability, offer encouragement that a deeper understanding of industrial innovation is within our grasp.

REFERENCES

Levin, Richard C., Klevorick, Alvin K., Nelson, Richard R. and Winter, Sidney G., "Survey Research on R&D Appropriability and Technological Opportunity: Part 1," Working Paper, Yale University, July 1984.

______ **and Reiss, Peter C.,** Tests of a Schumpeterian Model of R&D and Market Structure," in Zvi Griliches, ed., *R&D, Patents, and Productivity*, Chicago: University of Chicago Press, 1984, 175–204.

Scherer, F. M., "Market Structure and the Employment of Scientists and Engineers," *American Economic Review*, June 1967, *57*, 524–31.

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

Scott, John T., "Firm versus Industry Variability in R&D Intensity," in Zvi Griliches, ed., *R&D, Patents, and Productivity*, Chicago: University of Chicago Press, 1984, 233–48.

Spence, Michael, "Cost Reduction, Competition, and Industry Performance," *Econometrica*, January 1984, *52*, 101–21.