Innovation in Large and Small Firms: An Empirical Analysis

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We present a model suggesting that innovative output is influenced by R&D and market structure characteristics. Based on a new and direct measure of innovation, we find that (1) the total number of innovations is negatively related to concentration and unionization, and positively related to R&D, skilled labor, and the degree to which large firms comprise the industry; and (2) these determinants have disparate effects on large and small firms.

As Simon Kuznets (1962) observed, perhaps the greatest obstacle to understanding the role of innovation in economic processes has been the lack of meaningful measures of innovative inputs and outputs. More recently, there has been the development of new data sources measuring different aspects of technical change. These new sources of data have included measures of patented inventions from the computerization by the U.S. Patent Office (Bronwyn Hall et al., 1986; Adam B. Jaffe, 1986; Ariel Pakes and Zvi Griliches, 1980), better measures of research and development (John Bound et al., 1984, and F. M. Scherer, 1982), and stock market values of inventive output (Pakes, 1985). While several of these new and improved data sources have been used to examine the relationship between innovative activity and firm size, there have been virtually no studies able to apply a more direct measure of the innovative output. For example, the limitations of using patent data were significant enough to supplement them with renewal data (Pakes and Mark Schankerman, 1984). Further, while most of the empirical research has examined only the innovative activity contributed by relatively large firms, the innovative output of the smallest firms has received only scant attention and quantification.[1] Thus, most of the inferences which have been made about the causes of innovative activity have been based on observing only the behavior of larger firms.[2] Such inferences may be misleading since, as we show, almost half of the number of innovations are contributed by firms which employ fewer than 500 workers.

The purpose of this paper is to add to the literature on new measures examining technical change by introducing a more direct measure of innovative activity, to determine some of its basic properties, and to illustrate its use with a reduced form empirical model. We present a model which investigates the degree to which innovative output is affected by different industry characteristics, and the extent to which small and large firms respond differently to various stimuli. The econometric analysis enables the testing of

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[1]For a thorough review of the literature relating technical change to innovation activity, see Morton I. Kamien and Nancy L. Schwartz (1975), F. M. Scherer (1980), and Richard C. Levin et al. (1985).

[2]For example, Scherer (1965) related market structure to the number of patents for fewer than 500 of the largest U.S. corporations.

two hypotheses: (1) the degree to which *R&D* expenditures produce innovative output is conditioned by the market structure characteristics; and (2) as Sidney G. Winter (1984) suggests, small- and large-firm innovative activity respond to distinct technological and economic regimes.

In Section I of this paper, we introduce the new innovation data and compare them with the more traditional measures of technical change, including patented inventions and *R&D* expenditures. After presenting the model in Section II, cross-section regressions estimating the logs of the 1982 total number of innovations, large-firm innovations, small-firm innovations, and the small-firm innovation share for 247 four-digit SIC (Standard Industrial Classification) industries are presented in Section III. Finally, in Section IV, a summary and conclusion of the model and empirical results are provided. We find that innovative output increases with industry *R&D* expenditures at a less than proportional rate. While some of the appropriability measures, such as market concentration and unionization, are negatively related to innovation activity, the extent to which an industry is comprised of large firms is positively related to the total number of innovations. Similarly, we find considerable evidence supporting the hypothesis by Winter (1984) that innovation activity for small firms responds to a different technological and economic environment than does innovation activity for large firms.

I. The Innovation Data

The measure of innovative activity used in this paper is the number of innovations in each four-digit SIC industry recorded in 1982. The data, which were only recently released by the U.S. Small Business Administration,[3] consist of 8,074 innovations introduced into the United States in 1982. Of these innovations, 4,476 were identified as occurring in manufacturing industries. The Small Business Administration constructed this data base by examining over 100 technology, engineering, and trade journals, covering each manufacturing industry. From the sections in each trade journal listing innovations and new products, a data base consisting of the innovations by four-digit SIC industry was formed. The entire list of trade journals used to compile these data is available from the authors. The Small Business Administration defines an innovation as "a process that begins with an invention, proceeds with the development of the invention, and results in the introduction of a new product, process or service to the marketplace." (Keith L. Edwards and Theodore J. Gordon, 1984, p. 1) Because the innovations recorded in 1982 were the result of inventions made, on average, 4.2 years earlier, in some sense the innovation data base represents the inventions made around 1978 that were subsequently introduced to the market in 1982. The data were also checked for duplication. In fact, 8,800 innovations were actually recorded, but it was subsequently found that 726 of them appeared either in separate issues of the same journal or else in different journals. Thus, double counting was avoided. While the Small Business Administration does not claim that every single innovative activity is included in the data base, it does consider the data to be "comprehensive and reliable."

The innovation data were classified according to the industry of origin based on the SIC code of the innovating enterprise. The data were then classified into innovations by large firms, defined as firms with at least 500 employees, and innovations by small firms, defined as firms with fewer than 500 employees. For example, an innovation made by a subsidiary of a diversified firm would be classified by industry according to the SIC industry of the innovating subsidiary (enterprise) and not by the SIC industry of the parent firm. However, the innovation would be classified by size according to the size of the entire firm and not just by the size of the subsidiary.[4]

[3]For a more complete explanation of the data, see the Appendix.

[4]Because 67 innovations could not be classified according to firm size, the number of total innovations does not always equal the sum of large- and small-firm innovations.

TABLE 1—NUMBER OF INNOVATIONS AND THE RELATIVE INNOVATIVE ACTIVITY OF LARGE AND SMALL FIRMS IN THE MOST INNOVATIVE INDUSTRIES, 1982

Industry	Total Innovations	Large-Firm Innovations/ Small-Firm Innovations	Large Firm Employment/ Small-Firm Employment
Electronic Computing Equipment	395	0.696	16.544
Process Control Instruments	165	0.731	1.632
Radio and TV Communication Equipment	157	1.153	4.814
Pharmaceutical Preparations	133	9.231	19.408
Electronic Components	128	0.740	0.894
Engineering and Scientific Instruments	126	0.518	1.096
Semiconductors	122	3.138	5.757
Plastics Products	107	0.268	0.332
Photographic Equipment	88	8.778	18.231
Office Machinery	77	6.700	11.658
Instruments to Measure Electricity	77	0.596	2.077
Surgical Appliances and Supplies	67	4.154	3.566
General Industrial Machinery	67	4.154	0.976
Surgical and Medical Instruments	66	0.833	3.566
Special Industry Machinery	64	2.048	2.717
Industrial Controls	61	0.326	1.732
Toilet Preparations	59	2.278	5.289
Valves and Pipe Fittings	54	0.606	2.436
Electric Housewares and Fans	53	7.833	17.182
Measuring and Controlling Devices	52	0.067	0.866
Food Products Machinery	50	3.083	1.976
Motors and Generators	49	3.900	14.625
Plastic Materials and Resins	45	2.000	6.937
Industrial Inorganic Chemicals	40	4.000	4.917
Radio and TV Receiving Sets	40	8.750	13.925
Hand and Edge Tools	39	2.455	2.125
Fabricated Platework	38	3.222	1.597
Fabricated Metal Products	35	0.706	0.495
Pumps and Pumping Equipment	34	1.125	3.484
Optical Instruments and Lenses	34	0.571	1.179
Polishes and Sanitation Goods	33	0.684	2.937
Industrial Trucks and Tractors	33	0.650	6.404
Medicinals and Botanicals	32	5.400	4.376
Aircraft	32	31.000	111.111
Environmental Controls	32	2.200	3.566
Total	2,617	1.272	8.440

Source: U.S. Small Business Administration.

There are several other important qualifications which should be made concerning the innovation data. The trade journals report relatively few process, service, and management innovations and tend to capture mainly product innovations. The most likely effect of this bias is to underestimate the number of innovations emanating from large firms, since larger enterprises tend to produce more process innovations than do their smaller counterparts. However, because it was found that the large-firm innovations are more likely to be reported in trade journals than are small-firm innovations, the Small Business Administration considers the biases to be at least somewhat offsetting.

Table 1 lists the total number of innovations in those industries which had the greatest number of innovations in 1982, along with the corresponding ratios of large-firm innovation to small-firm innovation and large-firm employment to small-firm employment (also for 1982). Large firms are defined as firms with at least 500 employees and small firms are defined as firms with fewer than 500. In some industries, the large firms exhibit considerably more innovative activity than do their smaller counterparts, while in other industries the small firms are apparently more innovative. One potential concern might be that the significance and "quality" of the innovations vary considerably between large and small firms. Based on 4,938 of the innovations, the Small Business Administration classified each innovation according to one of the following levels of significance: (1) the innovation established an entirely new category of product; (2) the innovation is the first of its type on the market in a product category already in existence; (3) the innovation represents a significant improvement in existing technology; and (4) the innovation is a modest improvement designed to update an existing product. While none of the innovations in the sample were in the highest level of significance, 80 were in the second level, 576 in the third level, and 4,282 were classified in the fourth level. Within each level of significance, the distribution between large- and small-firm innovations proved to be remarkably constant. In both the second and third significance categories, the large firms accounted for 62.5 percent of the innovations and the small firms for the remaining 37.5 percent. In the fourth significance category, the large firms accounted for just a slightly smaller share of the innovations, 56.6 percent, while the small firms contributed the remaining 43.4 percent. A chi-square test for the hypothesis that there is no difference in the frequency of innovation with respect to innovation significance and firm size cannot be rejected at the 99 percent level of confidence (Edwards and Gordon, 1984).[5] Thus, based on the U.S. Small Business Administration's classification of the significance level of innovations, there does not appear to be a great difference in the "quality" and significance of the innovations between large and small firms. However, the extent of innovative activity does not necessarily correspond to the market values of the innovations. It is conceivable that larger firms may tend to focus on innovations with a higher market value.

The second column of Table 1 shows that while the number of large-firm innovations exceeded that of small firms in twenty-one of the thirty-five most innovative industries, the small firms were more innovative in the remaining fourteen. By contrast, the third column indicates that large firms accounted for a greater share of 1982 industry employment in all but five of these highly innovative industries. For the entire sample of manufacturing industries the simple correlation between these two measures is only 0.316. While the ratio of the innovations-per-employee is 6.64 times greater for small firms than for large firms for the most innovative industries, small firms were only 43 percent more innovative than their larger counterparts for the entire sample of manufacturing industries.[6]

Table 2 shows the distribution of manufacturing industries according to innovation frequency. About one-quarter of the innovating industries contributed at least sixteen innovations, while slightly more than one-half of these industries had fewer than six innovations.

In order to compare the new innovation measures with the more traditional measures of technical change, Table 3 provides a correlation matrix of input and output measures of innovative activity. There is a striking difference in the simple correlation of 0.481

[5]Unfortunately, no further information regarding the distribution of innovations by significance category has been released by the U.S. Small Business Administration. Therefore, no comparisons across industries can be made.

[6]It should be noted that while there were a total of 8,074 innovations identified in the data base, some innovations occurred outside of manufacturing and others were contributed from firms which could not be found in publishing company directories. While some of these were subsidiaries of large firms, many more were small companies. A random sample of 600 firms (with 375 responses) was used to allocate the entire set of innovations into 55 percent from small firms and 45 percent from large firms, resulting in an innovation-per-employee ratio 2.38 times greater in small firms than in large firms.

TABLE 2—THE DISTRIBUTION OF MANUFACTURING INDUSTRIES ACCORDING TO INNOVATION FREQUENCY

	Number of Innovations[a]							
	1–5	6–10	11–15	16–20	21–25	26–30	31 >	Total
Total Innovations	149	36	21	13	15	6	36	276
(percent)	(53.99)	(13.04)	(7.61)	(4.71)	(5.43)	(2.17)	(13.04)	(99.99)
Large-Firm Innovations	127	28	24	6	7	8	18	218
(percent)	(58.26)	(12.84)	(11.01)	(2.75)	(3.21)	(3.67)	(8.26)	(100.00)
Small-Firm Innovations	129	33	16	9	4	1	13	205
(percent)	(62.93)	(16.10)	(7.80)	(4.39)	(1.95)	(0.49)	(6.34)	(100.00)

Source: U.S. Small Business Administration.
[a]Only industries in which there is at least some innovation activity are included in this table.

TABLE 3—CORRELATION MATRIX OF INPUT AND OUTPUT MEASURES OF INNOVATIVE ACTIVITY

	Total Innovations	Large-Firm Innovations	Small-Firm Innovations	Total *R&D* Expenditures	Company *R&D* Expenditures
Large-Firm Innovations	0.920	–			
Small-Firm Innovations	0.922	0.698	–		
Total *R&D* Expenditures	0.481	0.532	0.379	–	
Company *R&D* Expenditures	0.746	0.737	0.672	0.764	–
Patents	0.467	0.482	0.382	0.327	0.440

between total *R&D* expenditures (also from the 1977 FTC Line of Business) and total innovations, and of 0.746 between company *R&D* expenditures and total innovations. That the correlation between company *R&D* and innovative activity is stronger than the correlation between total *R&D* and innovative activity is consistent with the findings by Griliches (1986) that privately financed *R&D* has a larger effect on private productivity and profitability than does government-financed *R&D*. The somewhat lower correlation between the *R&D* measures and the total number of patented inventions[7] between 1970 and 1972 is not surprising, as Pakes and Griliches (1980, p. 378) observe that "patents are a flawed measure (of innovative output); particularly since not all new innovations are patented and since patents differ greatly in their economic impact." Still, the correlation between the output measures, total innovations, and patents is greater than that between the *R&D* measures and patents. Also of interest is that, just as the correlation between innovations and *R&D* is greater for large firms than for small ones, the correlation between patents and innovations is greater for large firms than for small ones.

The relationships between the input and output measures of innovative activity are somewhat sensitive to the total amount of innovative activity. That is, in industries in which there is little innovative activity, defined as those with fewer than seven innovations, the correlation between all of the measures of technical change become considerably weaker. In particular, the correla-

[7]The correlations involving the patents are at the three-digit SIC level. (The corresponding variables were also aggregated to the three-digit SIC level.) All other correlations are for the four-digit SIC level.

TABLE 4—COMPARISON OF INNOVATION DATA WITH *R&D* AND PATENT MEASURES[a]

Industry Group	Total Innovations	Patents	Patents/ Innovation	Company *R&D* (millions)	*R&D* (millions)/ Innovation
Food and Tobacco	206	311	1.51	272	1.32
Textiles and Apparel	29	147	5.07	65	2.24
Lumber and Furniture	83	50	0.60	37	0.45
Paper	61	292	4.79	150	2.46
Chemicals (excluding drugs)	332	3,492	10.52	1,260	3.80
Drugs	170	868	5.11	449	2.64
Petroleum	24	1,046	43.58	360	15.00
Rubber and Plastics	129	637	4.94	287	2.22
Stone, Clay, and Glass	59	477	8.09	149	2.53
Primary Metals	74	424	5.73	239	3.23
Fabricated Metal Products	340	450	1.32	246	0.72
Machinery (excluding office)	612	1,657	2.71	852	1.39
Computers and Office Equipment	566	1,045	1.85	1,054	1.86
Industrial Electrical Equipment[b]	444	836	1.88	210	0.47
Household Appliances	64	232	3.63	78	1.22
Communications Equipment	262	2,384	9.10	1,136	4.34
Motor Vehicles and Other Transportation Equipment[c]	152	809	5.32	1,791	11.78
Aircraft and Engines	48	501	10.44	653	13.60
Guided Missiles and Ordnance	16	173	10.81	103	6.44
Instruments	736	1,351	1.84	652	0.89
Total[d]	4,407	17,182	3.90	10,043	2.28

[a]Company *R&D* (1974) and patent (June 1976–March 1977) data are from Scherer (1983).
[b]Includes SIC 361, 362, 364, and 367.
[c]Includes SIC 371, 373, 374, 375, and 379.
[d]Includes only industries in this table.

tion between large-firm innovations and patents falls to 0.107, while that between small-firm innovations and patents is nearly twice as great. Similarly, the correlation between each of the *R&D* measures and small-firm innovations falls to less than 0.070 while that between each of the *R&D* measures and the large-firm innovations is not so greatly affected. In addition, the correlation between patents and each of the *R&D* measures falls to below 0.100 for the low-innovative industries. In the high-innovative industries, defined as those with at least fifteen innovations, the correlation between small-firm innovations and patents is also considerably weaker, as is that between the *R&D* measures and small-firm innovations.

Table 4 provides a more detailed comparison of an input measure—company *R&D* expenditures (from the FTC Line of Business Survey)—and two output measures, the total number of innovations and the total number of patented inventions between June 1976 and March 1977 (from Scherer, 1983). As the simple correlation of 0.74 indicates, there is a fairly strong relationship between the ratio of patents-per-innovation and *R&D* expenditures (millions of dollars)-per-innovation.[8] Of particular interest is that the patent-per-innovation ratio in drugs is about one-half of that in the rest of the broader chemical sector. This is remarkably similar to the pattern of patents-per-scientists and engineers identified by Robert E. Evenson (1984). The relatively high ratios of patents-per-innovation in the chemical and petroleum sectors, and the relatively low ratios in the computers, electrical machinery, lumber, and instruments sectors is explained by Edwin Mansfield (1984, p. 462): "The value

[8]Patents represent 59 percent of all invention patents issued to U.S. corporations during the sample period and 61 percent of patents issued to industrial corporations (Scherer, 1983).

TABLE 5—WEIGHTED MEAN NUMBER OF TOTAL INNOVATIONS, SMALL-FIRM INNOVATION, AND EMPLOYMENT SHARES BY TWO-DIGIT SECTOR[a]

Sector	Total Innovations	Small-Firm Innovation Share	Small-Firm Employment Share
Food	3.739	0.228	0.220
	(1.977)	(0.052)	(0.175)
Textiles	0.333	0.133	0.325
	(0.062)	(0.161)	(0.156)
Apparel	0.576	0.099	0.565
	(0.605)	(0.159)	(0.220)
Lumber	0.647	0.088	0.564
	(0.338)	(0.228)	(0.264)
Furniture	5.539	0.365	0.596
	(0.422)	(0.074)	(0.264)
Paper	3.588	0.161	0.234
	(0.103)	(0.022)	(0.199)
Printing	1.471	0.191	0.524
	(0.368)	(0.048)	(0.245)
Chemicals	17.929	0.313	0.135
	(0.014)	(0.041)	(0.163)
Petroleum	4.800	0.400	0.113
	(2.400)	(0.200)	(0.163)
Leather	0.546	0.273	0.422
	(0.776)	(0.230)	(0.182)
Stone,	2.185	0.219	0.347
Clay, and Glass	(0.036)	(0.013)	(0.264)
Primary Metals	2.846	0.276	0.227
	(1.631)	(0.043)	(0.167)
Fabricated Metal	9.556	0.388	0.524
Products	(4.301)	(0.038)	(0.192)
Machinery	25.886	0.485	0.289
(nonelectrical)	(1.355)	(0.014)	(0.199)
Electrical	20.946	0.411	0.164
Equipment	(1.824)	(0.008)	(0.155)
Transportation	9.000	0.149	0.075
Equipment	(1.000)	(0.029)	(0.325)
Instruments	56.615	0.506	0.221
	(16.344)	(0.017)	(0.121)

[a]The sector means are weighted averages (by 1977 value-of-shipments) of the four-digit SIC industry values. The small-firm innovation share is defined as the percentage of total innovations contributed by small firms. The small-firm employment share is defined as the percentage of industry employment accounted for by firms with fewer than 500 employees. The data come from the U.S. Small Business Administration, Small Business Data Base, 1982. Standard deviations are listed in parentheses.

and cost of individual patents vary enormously within and across industries... Many inventions are not patented. And in some industries, like electronics, there is considerable speculation that the patent system is being bypassed to a greater extent than in the past. Some types of technologies are more likely to be patented than others."

A broader comparison of the distribution of the innovations classified according to firm size, both between and within two-digit SIC sectors is presented in Table 5. For example, the first column shows that the mean number of total innovations in the 47 industries (weighted by the 1977 value-of-shipments) comprising the food sector was 3.74. The second column shows the small-firm innovation share, measured as the percentage of total innovations contributed by small firms, and indicates that in certain sectors the mean number of innovations contributed by the large firms far exceeded the mean number contributed by small firms, while in other sectors the pattern is reversed. As the third column indicates, in about half of the sectors the small-firm employment share exceeds the small-firm innovation share, and in the other half the innovation share of small firms exceeds the employment share.

II. The Empirical Model

We follow others (Jaffe, 1986; Scherer, 1982; and Mansfield, 1981) and assume innovative output is related to innovation-inducing inputs in the previous period according to a log relationship. The independent variables we expect to be important are: *R&D* expenditures (either total or company), 1977; capital intensity, measured as gross assets divided by value-of-shipments, 1977; the four-firm concentration ratio, 1977; the mean percentage of employees belonging to a union between 1973 and 1975; advertising expenditures divided by value-of-shipments; the share of 1977 industry employment accounted for by large firms (enterprises with more than 500 employees); a measure of skilled labor, defined as the percentage of employment consisting of professional and kindred workers, plus managers and administrators, plus craftsmen and kindred workers, 1970. Finally, to control for industry size, the 1977 value-of-shipments is included in the empirical model. All variable sources are listed in the Appendix.

Concentration, advertising, and capital intensity have all been hypothesized to facilitate appropriability and therefore encourage innovation (William S. Comanor, 1967; and Kamien and Schwartz, 1975). More recently, several models have been developed arguing that unions capture rents from intangible capital investments, and, in particular, those accruing from innovation-producing *R&D* (Robert A. Connolly, Barry Hirsch, and Mark Hirschey, 1986; and Hirsch and Albert N. Link, 1986). To the extent to which unions are successful in such rent-seeking activities, the ease of appropriability by the innovative firm is clearly reduced. Therefore, a negative relationship between unionization and total innovative activity is expected.

By substituting the number of large-firm innovations and small-firm innovations as dependent variables into the regression model, the hypothesis by Winter (1984) that two technological regimes exist can be examined. According to Winter (1984, p. 297), "An entrepreneurial regime is one that is favorable to innovative entry and unfavorable to innovative activity by established firms; a routinized regime is one in which the conditions are the other way round." To the extent to which innovations from small and large firms emanate from different technological regimes, a difference in the parameters in the small- and large-firm innovation equations would offer support for Winter's hypothesis that large- and small-firm innovations are promoted under differing economic and technological conditions.[9] The relative small-firm innovative advantage "is likely to be roughly proportional to the number of people exposed to the knowledge base from which innovative ideas might derive." (Winter, 1984, p. 297)

While the exact dynamic relationship between the endogenous and exogenous variables is not known, this should not pose a significant problem in the context of cross-sectional analysis where each of the industry-specific attributes remains relatively invariant over time. While this model assumes the traditional view that technical change is endogenous to market structure, Partha Dasgupta and Joseph Stiglitz (1980) argue that, in fact, certain aspects of market structure are endogenous to technical change.

III. Regression Results

Using the logged value of the number of total innovations in 1982 as the dependent

[9]While we have seen a major shift in the twentieth century, with the large firm and the industrial research laboratory playing a much more important role in innovation, individual entrepreneurs, who are not associated with established firms (Joseph Schumpeter, 1934, p. 62), continue to survive and thrive in a number of industries (Kenney Martin, 1986).

TABLE 6—REGRESSIONS OF LOG OF TOTAL NUMBER OF INNOVATIONS
(*t*-statistics in parentheses)

	1	2
Log Total *R&D*	0.364	–
	(6.434)[a]	
Log Company *R&D*	–	0.409
		(7.424)[a]
Log Capital/Output	0.007	−0.040
	(0.045)	(−0.278)
Log Concentration	−0.613	−0.631
	(−3.853)[a]	(−4.061)[a]
Log Unionization	−0.460	−0.425
	(−3.078)[a]	(−2.907)[a]
Log Advertising	−0.061	−0.056
	(−1.169)	(−1.096)
Log Large-Firm Employment Share	0.438	0.400
	(2.170)[a]	(2.023)[a]
Log Skilled Labor	0.505	0.559
	(2.257)[a]	(2.620)[a]
Log Industry Size	0.032	0.621
	(0.372)	(4.301)[a]
Constant	1.883	1.821
	(1.251)	(1.492)
Sample Size	247	247
R^2	0.457	0.482
F	25.040[a]	27.730[a]

[a]Statistically significant at the 95 percent level of confidence, two-tailed test.

variable, the cross-section regressions for 247 four-digit SIC manufacturing industries are shown in Table 6. While equation (1) uses the measure of total expenditures on *R&D*, equation (2) uses company expenditures on *R&D*. There are two major results from this table. First, the negative coefficient of concentration suggests that lower, and not higher, levels of concentration tend to be associated with increased innovation activity. While the emergence of a negative and significant relationship is consistent with the findings of Connolly and Hirschey (1984), it is a much stronger result than found by Scherer (1965). Second, the elasticity of both company and total *R&D* with respect to the total number of innovations is considerably less than one. Even when the measure of company *R&D*, which apparently explains innovative activity better than total *R&D*, is used in equation (2), the elasticity of *R&D* remains below 0.5. This is somewhat less than the elasticity of about one found between firm *R&D* and patents by Bound et al. (1984).

The positive coefficient of the large-firm employment share indicates that the greater the proportion of an industry consisting of firms with more than 500 employees, the greater is the innovation activity. Of the other variables representing appropriability, only unionization apparently is negatively associated with the total number of innovations, providing support for the Hirsch and Link (1986) hypothesis.[10]

Table 7 shows the results for analogous regressions where the log of the number of large-firm innovations, log of the number of small-firm innovations, and the small-firm innovation share are the dependent variables. Since the error terms in the large- and small-firm innovation regressions are presumably interrelated, the generalized least squares method for seemingly unrelated regressions was estimated using the Aitken procedure (Jan Kmenta, 1971). Skilled labor and advertising apparently have disparate relationships with small- and large-firm innovations. While skilled labor is positively and advertising negatively associated with small-firm innovations, neither is statistically associated with large-firm innovations. Although concentration is negatively associated with both large- and small-firm innovation, the elasticity of concentration with respect to small-firm innovations is more than double that for large firms. A perhaps somewhat surprising result is that not only is

[10]Regressions analogous to those in Table 6 were estimated substituting the patent measure used in Table 3 as the dependent variable. The results are quite similar to those using the innovation measure in Table 6. Total *R&D*, capital/output, the large-firm employment share, and skilled labor are found to be positively related to the number of patents, while concentration is negatively related to patents. Neither advertising, which has a negative coefficient, nor unionization, which has a positive coefficient, can be considered statistically significant. Thus, substituting the patent measure for the innovation measure yields very similar results. Only unionization and capital/output have different qualitative relationships between the patent and innovation measures.

TABLE 7—REGRESSIONS OF THE LOG OF THE NUMBER OF LARGE- AND SMALL-FIRM INNOVATIONS, AND THE SMALL-FIRM INNOVATION SHARE (*t*-statistics listed in parentheses)[a]

Equation	Total *R&D*	Company *R&D*	Concentration	Capital/ Output	Unionization	Advertising	Large-Firm Employment Share	Skilled Labor	Industry Size	Constant	Sample Size	R^2	F
1													
Large-Firm	0.251	–	−0.276	0.107	−0.415	−0.042	0.371	0.294	0.150	0.020	247	0.372	–
Innovations	(4.711)[c]		(−1.836)[b]	(0.763)	(−2.937)[c]	(−0.854)	(1.943)[b]	(1.388)	(1.825)[b]	(0.017)			
2													
Small-Firm	0.278	–	−0.705	−0.060	−0.442	−0.082	0.437	0.383	−0.158	3.802	247	0.366	–
Innovations	(5.850)[c]		(2.036)[c]	(−0.481)	(−3.517)[c]	(−1.866)[b]	(2.572)[c]	(2.036)[c]	(−2.155)[c]	(1.056)			
3													
Large-Firm	–	0.294	−0.294	0.078	−0.388	−0.038	0.339	0.318	0.110	−0.022	247	0.393	–
Innovations		(5.612)[c]	(−1.987)[c]	(0.568)	(−2.785)[c]	(−0.787)	(1.802)[b]	(1.567)	(1.361)	(−0.019)			
4													
Small-Firm	–	0.324	−0.723	−0.093	−0.412	−0.078	0.401	0.411	−0.202	3.756	247	0.398	–
Innovations		(7.015)[c]	(−5.556)[c]	(−0.769)	(−3.356)[c]	(−1.813)[b]	(2.423)[c]	(2.300)[c]	(−2.842)[c]	(3.669)[c]			
5													
Small-Firm	−0.389	–	−0.004	−0.505	−0.001	−7.306	0.355	0.785	−0.154	0.168	247	0.117	3.94[b]
Innovation	(−1.765)[b]		(−2.811)[c]	(−3.077)[c]	(0.569)	(−0.456)	(2.535)[c]	(2.881)[c]	(−0.367)	(1.459)			
Share													
6													
Small-Firm	–	−0.138	−0.004	−0.484	−0.001	−7.194	0.330	0.666	−0.400	0.209	247	0.116	3.92[b]
Innovation		(−0.463)	(−2.837)[c]	(−2.934)[b]	(0.637)	(−0.446)	(2.327)[c]	(2.482)[c]	(−0.903)	(1.834)[b]			
Share													

[a]The method of generalized least squares (Aitken procedure) was used to estimate large-firm innovations and small-firm innovations. The logs for all explanatory variables are used to estimate log large-firm innovations and log small-firm innovations but not for the small-firm innovation share.
[b]Statistically significant at the 90 percent level of confidence, two-tailed test.
[c]Statistically significant at the 95 percent level of confidence, two-tailed test.

the coefficient of the large-firm employment share positive and significant for small-firm innovations, but it is actually greater in magnitude than for large firms. This suggests that, *ceteris paribus*, the greater extent to which an industry is composed of large firms, the greater will be the innovative activity, but that increased innovative activity will tend to emanate more from the small firms than from the large firms. Perhaps this indicates that, in industries composed predominately of large firms, the existing small firms must resort to a strategy of innovation in order to remain viable. This is consistent with the findings of Richard E. Caves and Thomas A. Pugel (1980) that smaller firms in an industry tend to perform better if they use different strategies from those followed by the larger firms.[11]

Equations (5) and (6) address a slightly different question. Rather than considering what determines the extent of innovative activity in small firms, small-firm innovative activity is examined relative to that in the entire industry.[12] The small-firm innovation share, or the number of small-firm innovations divided by the number of total innovations, is used as the dependent variable. The negative coefficients of total *R&D*, concentration, and capital/output, suggest that the number of small-firm innovations tends to be small relative to that in the entire industry in industries which are high in *R&D*, capital-intensive, and which are concentrated. The positive coefficients of the large-firm employment share and skilled labor imply that the innovation activity of small firms is high relative to the industry level in in-

[11]The disparate effect of the large-firm employment share on small- and large-firm innovation rates is perhaps implied by Scherer (1980, p. 422), "...the most favorable industrial environment for rapid technological progress would appear to be a firm size distribution that includes a predominance of companies with sales below $500 million, pressed on one side by a horde of small, technologically oriented enterprises bubbling over with bright new ideas and on the other by a few larger corporations with the capacity to undertake exceptionally ambitious developments."

[12]For further analysis of the difference between large- and small-firm innovation rates, see our 1987 paper.

TABLE 8—HYPOTHESES TESTS FOR THE DIFFERENCES IN THE DETERMINANTS OF INNOVATION BETWEEN LARGE AND SMALL FIRMS (BASED ON REGRESSIONS 3 AND 4 IN TABLE 7)

Variable Hypothesized[a]	SSR[b]	F
Company *R&D*	118.21	3.665[d]
Capital/Output	120.80	0.279
Concentration	118.25	3.625[d]
Unionization	120.71	0.398
Advertising	120.73	0.359
Large-Firm Employment Share	120.73	0.359
Skilled Labor	118.23	3.630[d]
All Variables[c]	104.276	2.731[d]

[a]The variable hypothesized and therefore constrained to have an identical effect on large-firm innovations and small-firm innovations. Each hypothesis is tested by comparing the sum of the squares explained by the regression from the regression with the restricted coefficient to that from the unrestricted regression. For further explanation of the hypothesis test, see Kmenta (1971).

[b]SSR refers to the sum of squares explained by the estimated regressions for small-firm innovations with the restricted coefficient.

[c]The coefficients of all the explanatory variables are constrained to be identical for the large-firm innovation and small-firm innovation equations.

[d]Statistically significant at the 95 percent level of confidence.

dustries in which there is only a small share of small firms, and in which skilled labor plays an important role.

The results from Table 7 do not support an unequivocal conclusion regarding the exact differences in innovation behavior between large and small firms. While the first four equations imply that skilled labor, advertising, and perhaps concentration and the large-firm employment share, account for the different patterns in innovative activity between large and small firms, the last two equations suggest that total *R&D*, concentration, capital/output, large-firm employment share, and skilled labor account for the differences in relative innovative activity. Thus, in Table 8 the hypotheses that each variable has an identical effect on small- and large-firm innovation activity are tested. The resulting *F*-test is statistically significant for skilled labor, company *R&D*, and concentration, as well as for the hypothesis that all of the variables jointly have an identical effect on small- and large-firm innovation activity. Thus, while there still remains ambiguity regarding the exact patterns between *R&D*, appropriability, and innovation activity for large and small firms, there is considerable support for Winter's (1984) hypothesis that different economic and technological regimes may account for at least some of the differences between the innovation activity of large and small firms.

IV. Conclusion

We have introduced a new and more direct measure of innovative activity in this paper and found that, while the total number of innovations is closely related to *R&D* expenditures (particularly after excluding federal *R&D*), and patented inventions, especially at the more aggregated level, the exact relationship between *R&D* and innovation is somewhat different from that between *R&D* and patents. While Bound et al. (1984) found that, based on firm data, the elasticity of *R&D* expenditures with respect to patented inventions is about one, we find that the number of innovations increases with increased industry *R&D* expenditures but at a decreasing rate. Similarly, while the literature has found a somewhat ambiguous relationship between concentration and various measures of technical change, our results are unequivocal—industry innovation tends to decrease as the level of concentration rises. In addition, there is evidence supporting the hypothesis that unionization is negatively related to innovation activity. Of course, these results are at best an introduction of the innovation data and need to be qualified, particularly in light of the likely simultaneity between industry technology and market structure. Future research may be able to incorporate the endogeneity of market structure in a manner suggested by Levin and Peter Reiss (1984).

This paper has also provided evidence supporting Winter's (1984) prediction that the innovation activity of small and large firms responds to considerably different technological and economic environments.

These findings are not without ambiguity. Further research should apply the patent measure in a similar framework to determine whether its performance differs from that of the innovation measure used here.

APPENDIX: DATA SOURCES AND FURTHER EXPLANATIONS

The data on innovations and employment for small and large firms come from the U.S. Small Business Administration (Edwards and Gordon, 1984). These data can be obtained upon request from the authors. The U.S. Department of Commerce, Bureau of the Census, *Annual Survey of Manufactures*, 1977, *Industry Profiles*, Washington: USGPO, issued 1981, is the source for capital/output (gross assets divided by value-of-shipments), concentration, and value-of-shipments. The advertising measure was derived by using the value-of-shipments data described above and advertising expenditures, from the 1972 U.S. Input-Output Table.

The unionization data are from Richard B. Freeman and James L. Medoff (1979). The percentage of total employment that is unionized for three-digit SIC industries between 1973 and 1975 is reported. We repeat these three-digit SIC values at the four-digit level. The measure of skilled labor is from the U.S. Department of Commerce, Bureau of the Census, Census Population 1970, Subject Report PC (2)-7C, *Occupation by Industry*, Washington: USGPO, issued 1972.

The total *R&D* and company *R&D* data are from the 1977 Federal Trade Commision Line of Business Report. The patent measure used for the disaggregated three-digit SIC correlations in Table 3 is from the Office of Technology Assessment and Forecast of the U.S. Patent Office. Both the patent and skill measures are taken from the *U.S. International Trade Commission's Industrial Characteristics and Trade Performance Data Bank*, June 1975, Office of Economic Research, Washington, D.C. The USITC data bank is described by Edward J. Ray (1981) and these measures are available from the authors on request.

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