Technical Performance and Firm Size: Analysis of Patents and Publications of U.S. Firms

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ABSTRACT. This study focuses on the scientific output of firms of different sizes in different industries in the U.S. Both patents, and papers and publications are used as measures of technical output. Data from two samples of firms, one consisting of 225 large firms (annual sales at least $250 million and minimum annual R&D budget of $1 million) and the other consisting of 248 small and medium sized firms (annual sales between $10 to $200 million and annual R&D budget at least $10 thousand) have been presented here. The study shows that determinants of R&D expenditure are different in firms of different sizes. For the large firms, R&D expenditure depends on net income as well as its size, measured in terms of annual sales. For small size firms, R&D expenditure is closely related with sales, rather than the net income. For large firms, R&D expenditure is related to both sales and income, the latter being more important than the former. The two output measures, patents and papers are correlated, but the correlation is not a very strong one for small firms. Patent and papers are correlated significantly with both R&D expenditure as well as annual sales. The firm's growth is not linked with patents. On the contrary, there is a negative relationship between patent and R&D growth and patent and income growth in the case of small firms. Papers are not linked with growth variables for small firms. Finally, this study confirms the hypothesis that small firms are more productive in innovation than the large firms. Small firms are more efficient than their larger competitors in terms of patents and papers per million dollars of R&D expenditure.

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This study focuses on the scientific output of firms of different sizes in different industries in the U.S. Firm size has been of particular interest here as we have witnessed some recent major merger activities giving rise to consolidation and restructuring in many industries. According to Kamien and Schwartz (1975), beyond some magnitude, size does not appear especially conducive to either innovational effort or output. The Bolton Committee concluded that small firms contributed 10% of all industrial innovations in the U.K. while accounting for only 5% of R&D expenditure (Freeman, 1971). Very large firms on the other hand, accounted for 54% of R&D expenditure and accounted for 20% of all innovations. Pavitt, Robson, and Townsend (1987) have concluded that "companies with less than 1,000 employees commercialized a much greater share than is indicated by their share of R&D expenditure". Edwards and Gordon (1984) found that small firms produced 745 innovations per million employees while large firms generated only 313 innovations per million employees.

Although Edwards and Gordon (1984) found small firms to be more productive per employee in innovation, larger firms were more innovative in industries where 4-firm concentration was 21 to 40%. Small firms were four times as innovative per employee as large firms in industries with concentration ratios of 41 to 60%. Acs and Audretsch (1987) have supported the modified Schumpeterian hypothesis about imperfect market structure and benefits from innovation. Large firms seem to have an innovative advantage in industries with high levels of concentration as well as capital and advertising intensity. Small firms derive innovative advantages in the early stages of life cycle in an

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industry when total innovation and skilled labor play important role. Acs and Audretsch (1988) found that the number of innovations increases with firm size at a decreasing rate. They also found unequivocally that innovation decreases with concentration.

A study of 130 largest U.S. firms by Soete (1979a) has shown that firms tend to carry out proportionately more R&D with increases in firm size, but at the same time tend to patent less. This finding supports an earlier conclusion by Scherer (1965).

We have focused on technical performance of industrial firms, both large and small, as there has been increasing concern for the technological competitiveness of the U.S. (President's Commission, 1985).

Several studies have pointed out that the innovative output of the U.S. has slowed down (Baily and Chakrabarti, 1988; Chakrabarti, 1988; Chakrabarti, Feinman, Fuentivilla, 1982; Glisman and Horn, 1988). In this paper we have investigated the technical performance of firms in different industries, both small and large, and the correlates of performance at a macro level. We have used both patents, and papers and publications as measures of technical output.

Industry samples

Small and medium size firms sample. Our sample is from the population of firms listed in the COMPUSTAT database of public companies. Our criteria for sample selection were as follows: (a) annual sales in 1986 must be between $10 to $200 million; (b) annual R&D expenditure during the period from 1977 to 1986 must be at least $10 thousand; and (c) annual R&D expenses showed a growth of 10% during this time period. These criteria enabled us to obtain the sample of firms who were within a specific range of size and were involved in R&D in some serious and systematic way. We identified 248 companies by these criteria. We obtained data for these companies for the period 1977—1986.

Large firms sample. The sample of large firms was developed from the list of public companies in the manufacturing sector having (a) minimum annual sales of $250 million (b) an annual R&D budget of $1 million (c) annual R&D budget at least 1% of sales. 225 companies were selected by this criteria. We obtained data for these companies for the period 1975—1983 (Halperin and Chakrabarti, 1987).

It may be mentioned that the studies reported by Soete (1979b) and Griliches (1984) used similar source of data, i.e. R&D surveys by *Business Week*. We have stratified the sample by imposing the additional conditions as explained above.

Variables and sources of data

From COMPUSTAT we obtained the data on the following variables: Sales, R&D expenditure, Average Sales during 1977—1986, Net Income and the main SIC number for the company.

The growth rates for sales, R&D and income are computed as the regression coefficient of the trend of the respective variables during the time period. The growth rate for income was not calculated for the companies which did not have consistent positive earning.

R&D expenditure data were obtained from *Business Week* for the group of companies in our large firm sample as that was the best source available at the time when we conducted the study in 1985—86.

Patent information. We used BRS/PATSEARCH, an online database to search for the patents issues to these firms during 1977 to date. This on-line database contains all utility patents, reissue patents and defensive patents issued by the U.S. Office of Patents and Trademarks since 1975. To ensure complete coverage, we searched for the patents issues to the subsidiaries of these firms, if they had any. (See Halperin, 1986 for details about the technique of database search)

Publications information. We obtained the information on papers and publications from SCISEARCH, a machine readable multidisciplinary index to the literature on science and technology prepared by the Institute of Scientific Information (ISI). All articles, reports of meetings, letters, editorials, correction notices from over 3000 major scientific and technical journals are indexed in SCISEARCH. We obtained the number of

papers and publications published by authors with the affiliation with the respective firms (or their subsidiaries) from 1972 to 1986 for the small firm sample. For the large firm sample the data on papers corresponded to the time period 1975–83.

Industry characteristics. We used the definition by Lawrence (1984) to categorize firms into five classes: high technology, capital intensive, labor intensive, resource intensive and service. High technology industries require a high proportion of R&D or employment of scientists and engineers. Firms in capital intensive industries use standardized technologies and employ more capital than labor in production. Firms in labor intensive industries use labor intensive technologies. Firms in resource intensive industries use natural resources as their main input. We classified the sample firms into these categories by matching their four-digit SIC codes with those of Lawrence (1984, Appendix 1).

Characteristics of the two samples

Table I provides the information on the firms in our two samples. The table indicates the differences between the two groups of samples. It is interesting to note that the large firms as a group have financially performed quite well in this period. Their growth rate in sales, income as well as R&D expenditure have been much better than the small and medium size firms. This points to the competitive stress in which the smaller firms have to operate. This table also points out that smaller firms have a better record of patents compared to their size, while the large firms tend to publish more.

Table II provides the data on the industry characteristics of the two samples of firms investigated in this paper. Both samples had a large number of firms in the high tech industry. The sample for large firms had very few firms in the labor intensive industry. The sample for smaller firms, on the other hand, had only a few firms in the resource intensive industry.

TABLE I
Characteristics of the two samples

Variables	Small firm sample $N = 248$	Large firm sample $N = 225$
Av. annual sales	64.68	3479.00
Av. annual R&D expenditure	2.39	82.30
Annual income	1.82	180.40
Annual R&D growth	20.47%	54.93%
Annual sales growth	10.09%	47.78%
Annual income growth	11.17%	39.45%
Patent/CO/year	2.12	50.46
Paper/CO/year	0.55	43.29

Results

Correlates for research & development expenditures. R&D expenditure is closely related to the annual sales for, both large and small firms. As shown in Table III, this relationship is stronger in larger firms. Another important observation is that the R&D budget is strongly correlated with income for only large firms.

The growth rate in R&D is linked with sales growth for all firms; the relationship is stronger in the case of smaller firms. Table III also indicates that smaller firms are likely to spend more money in R&D as their income grows. This is not so in the case of large firms.

Inter-relationship between measures of R&D output. The two measures of R&D output, patents, and papers are related to each other as shown in

TABLE II
Industry characteristics of the two samples

Industry	Small firm sample $N = 248$	Large firm sample $N = 225$
Hitech*	178	132
Capital intensive	28	28
Resource intensive	7	51
Labor intensive	26	Na
Other	9	14

* Definition of these industries was according to Lawrence 1984. Hitech category included firms in chemical, electrical and electronics, machine tools and machinery, and instruments industries. 'Others' included firms in the service sector such as oil services, health care.

TABLE III
Correlates for R&D expenditures

Variables	Small firm sample $N = 248$	Large firm sample $N = 225$
R&D budget, sales	0.43**	0.75**
R&D budget, income	−0.11	0.83**
R&D growth, sales growth	0.78**	0.41**
R&D growth, income growth	0.49**	−0.01

* Indicates significant at 0.05 level.
** Indicates significant at 0.01 level.

Table IV. The correlation coefficients among them are significant at 0.01 level. We observe that the simple correlation between patent and papers for the large firms is higher than that for smaller firms. When we controlled for the size of the firms in our correlation analysis by computing the partial correlation, we find that the correlation is significantly lower for the large firm sample, but not for the small firms. Moreover the partial correlations for these two samples are close to each other.

Correlates of patents. Table V provides the data on correlates for patents. The total number of patents and size are correlated as expected. We have two indicators of size, average sales and average R&D expenditure. For both the samples, the relationships are significant beyond 0.01 level. However, for the sample of large firms, the relationship is stronger. For the large firms, patents and income are strongly correlated. We do not observe any statistically significant relations between income and patents for the small firms. Another important

TABLE IV
Correlation between paper and patents

Small firms sample $N = 248$		Large firms sample $N = 225$	
Correlation	Partial correlation controlling sales	Correlation	Partial correlation controlling sales
0.32	0.29	0.79	0.39

Note: All correlations significant at 0.01 level.

TABLE V
Correlates for patents

Variables	Correlation coefficients: Small firm sample $N = 248$	Correlation coefficients: Large firm sample $N = 225$
R&D expenditure	0.36**	0.64**
Sales	0.31**	0.56**
Income	0.10	0.60**
R&D growth	−0.11*	0.05
Sales growth	−0.06	0.06
Income growth	−0.18*	−0.01

* Significant at 0.05 level.
** Significant at 0.01 level.

observation is that patent is not correlated with the growth related variables. If anything, we find a negative relationship between patent and R&D growth as well as income growth for the sample of small firms.

Correlates of publications. Table VI provides the data on the correlates of papers and publications. Papers are correlated with R&D expenditure much more strongly than with sales for both large and smaller firms. These relationships are much stronger in the case of large firms. In the case of large firms, income and papers are strongly correlated. Interestingly, none of the growth variables are significantly related with papers.

Firm size and R&D productivity. Are small firms more productive than large firms? We have

TABLE VI
Correlates for papers and publications

Variables	Correlation coefficients: Small firm sample $N = 248$	Correlation coefficients: Large firm sample $N = 225$
R&D expenditure	0.44*	0.69**
Sales	0.14*	0.48**
Income	−0.03	0.67**
R&D growth	0.07	0.07
Sales growth	0.09	0.09
Income growth	−0.09	0.01

* Significant at 0.05 level.
** Significant at 0.01 level.

examined this question in our study. Halperin and Chakrabarti (1987) have observed that in large firms both patents and publications increase less proportionately with sales for the largest 100 firms. This finding is consistent with Scherer's (1965) findings. For the second sample of firms, however we did not see such relationship. Table VII provides the concentration data on the firms in our two samples.

To investigate the R&D productivity further, we computed the number of patents and papers per million of dollars of R&D for groups of companies of different sizes in our two samples. Table VIII provides the data on these variables for the small firm and Table IX for the large firm sample.

We plotted the R&D productivity, both patent and papers, against the log of sales for the two samples. Figure 1 shows the plot for the large firm sample and Figure 2 for the small firm sample.

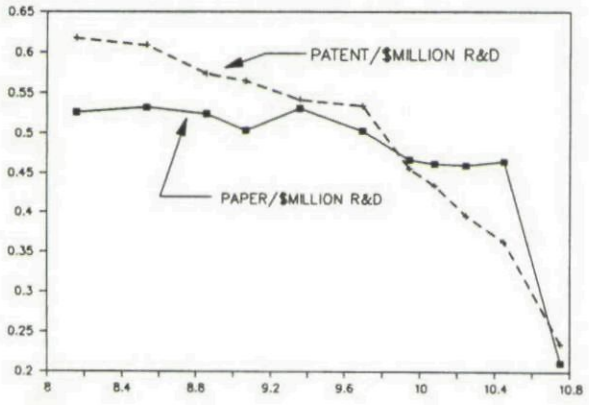

Fig. 1. Technical productivity: Large firms.

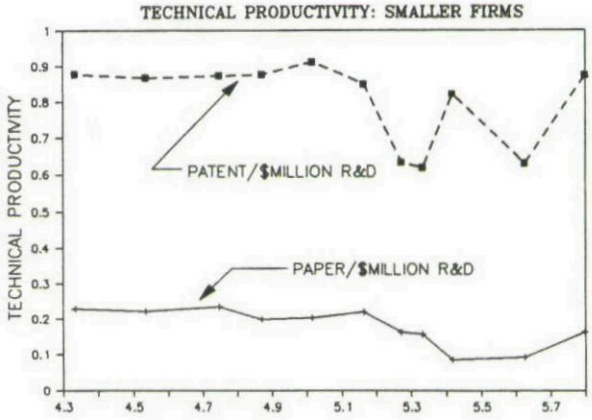

Fig. 2. Technical productivity: Smaller firms.

From Table VIII, we note that patent productivity is quite high for the small firm sample. The patent productivity did not change drastically with changes in the size of the firms in this group. Second, paper productivity is much less compared with patent productivity. This means that the small firms put much more emphasis on patents than on papers. However, paper productivity went up as the size went down. These are represented in Figure 2.

In Table IX, we observe that patent productivity went up with decreasing firm size. The same is true for paper productivity. When we compare the two tables, we find that large firms are much more productive in producing papers than the small firms, but not patents. From Figure 1, we observe that both patent and paper productivity (per million dollars of R&D) systematically went down with increasing firm size.

TABLE VII
Comparison of concentration of papers, patents and sales

	Small firm sample			Large firm sample		
Size	Sales	Patents	Paper	Sales	Papers	Patents
First 4	8.31%	3.24%	2.32%	23.70%	7.20%	7.90%
First 8	13.96%	5.71%	3.21%	35.20%	25.70%	19.60%
First 12	17.02%	8.75%	3.45%	43.20%	29.70%	24.90%
First 16	20.84%	10.06%	9.77%	48.70%	30.70%	28.20%
First 20	24.52%	10.89%	10.66%	53.30%	35.60%	34.70%
First 30	33.02%	22.63%	22.50%	62.40%	48.20%	50.00%
First 50	47.44%	39.56%	33.74%	74.00%	73.80%	61.30%
First 75	61.61%	50.15%	43.56%	83.00%	79.20%	72.80%
First 100	72.69%	63.32%	64.87%	89.60%	88.50%	81.00%
First 150	88.05%	81.12%	79.63%	97.30%	98.20%	95.70%
All	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

TABLE VIII
Firm size and R&D productivity for sample of smaller firms

Size	(Per $million R&D) Patent	Paper	Av sales for the group
4	0.873	0.163	330.01
8	0.630	0.092	277.12
12	0.822	0.085	225.24
16	0.619	0.157	206.88
20	0.634	0.162	194.68
30	0.850	0.220	174.80
50	0.912	0.203	150.68
75	0.877	0.199	130.45
100	0.874	0.234	115.44
150	0.867	0.222	93.23
248	0.869	0.229	64.91

Summary and conclusions

Most studies on R&D output have used unidimensional measures of performance indicator. Economists have perferred patents, sociologists have used papers and publications (and other communicative acts) as measures of R&D output. Management and policy researchers have focused on new products as the indicators. Halperin and Chakrabarti (1987) attempted to investigate the firm's behavior in terms of both patents and papers indicators in large U.S. firms. We have extended that research to small and medium size firms in different industries and have compared the results from these two studies in this paper.

TABLE IX
Firm size and R&D productivity for sample of large firms

Size	(Per $million R&D) Patent	Paper	Av sales for the group
First 4	0.211	0.235	46654.97
First 8	0.465	0.3633	4429.31
First 12	0.460	0.396	28127.15
First 16	0.462	0.434	23812.38
First 20	0.467	0.456	20824.08
First 30	0.503	0.534	16256.77
First 50	0.531	0.542	11570.64
First 75	0.504	0.565	8657.066
First 100	0.524	0.574	7017.915
First 150	0.532	0.609	5079.14
First 225	0.526	0.618	3479.610

We have observed that determinants of R&D expenditure are different in firms of different sizes. For the large firms, R&D expenditure depends on net income as well as its size measured in terms of annual sales. For smaller size firms, R&D expenditure is closely related with sales, rather than the net income. For the smaller size firms, the growth rate of R&D is closely related with growth rates of sales and net income.

For large firms, growth rate in sales leads to a proportionate growth in R&D, but growth in income does not lead to a proportionate growth in R&D. For larger firms, R&D is determined by its size as available cash.

The two output measures, patents and papers are correlated, but the strength of correlation is not a very strong one for smaller firms. When we controlled for size and computed the partial correlation, we observe a much weaker relationship between papers and patents for the large firms. Our explanation is that there may be an inherent conflict between patents and papers. Patents and papers are probably substitutes for each other. Scientists may not publish on an invention because that may be proved a hindrance to obtaining a subsequent patent on it (Halperin and Chakrabarti, 1987).

Patents and papers are correlated significantly with both R&D expenditure as well as annual sales. The strength of correlation is much stronger for the larger firms than for the smaller firms. This may be due to the fact that larger firms may encourage patenting and publishing more than the smaller firms.

The firm's growth is not linked with patents. If anything, we observe a negative relationship between patent and R&D growth and patent and income growth in the case of smaller firms. Papers are not linked with growth variables for smaller firms. Rates of growth in both sales and income have a significant correlation with R&D expenditure in small firms. For large firms, we observe a correlation between sales growth and R&D expenditure only.

Interpretation of the results of our study should take into account other variables and contextual conditions of the specific industries as well as firms. According to Rothwell and Zegveld (1982), smaller firms play a significant role in innovation

in the earlier phase of a technology while larger firms benefit from process and other incremental innovations in the later stage of the technology's life cycle where economies of scale become important in a mass market. Instead of providing a definitive conclusion about the relative innovativeness or efficiency of smaller firms in the innovation process, we would echo the conclusions of Acs and Audretsch (1989) challenging the conventional wisdom of public policy favoring large firms.

Importance of the contextual conditions has been underscored by Levin and his associates in their survey of R&D executives in 130 industries in the U.S. According to Levin *et al.* (1985), R&D spending is encouraged in young industries where a strong science exists and where the government makes large contributions to technological knowledge.

A further analysis of the data from the small firms sample, has shown that the relationship between R&D expenditure and patents and publications are different for different industries such as chemical, electrical, machinery and instruments (Chakrabarti, 1990). The opportunities for patenting and usefulness of patents as a competitive weapon vary from industry to industry. This may partly explain the differences in propensity to patent and publish. Focussing on the new products, it was found that the average number of new products generated per million dollars of R&D in the electrical industry was 2.078, while the same for the instrument industry was 1.158. This points to the need for a better understanding of the contextual conditions of the specific industries.

Are smaller firms more efficient than the large firms? The answer to this question is not clear. One of the major problem is that many small firms do not report R&D expenditures in the same way as the large firms. The problem is one of definition about what constitutes R&D. It appears to us that the more important question to examine is how the challenges of technological innovation are met by the small and large firms under different stages of the technology life cycle. As Chakrabarti (1990a) has shown from a longitudinal study of three industries, chemicals, textiles and machine tools, productivity and innovation are related with each other. Different industries have dealt with the problems quite differently through the nature of R&D work undertaken by them which in turn have been reflected in their technical output.

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References

Acs, Zoltan J. and David B. Audretsch, 1987, 'Innovation, Market Structure, and Firm Size', *Review of Economics and Statistics* **69** (4), 567—574.

Acs, Zoltan J. and David B. Audretsch, 1988, 'Innovation in Large and Small Firms: An Empirical Analysis', *American Economic Review* **78** (4), 678—690.

Acs, Zoltan J. and David B. Audretsch, 1989, *Small Firms and Technology*, Ministry of Economic Affairs, Directorate of Technology policy, The Hague, Netherlands.

Baily, Martin Neil and Alok K. Chakrabarti, 1988, *Innovation and the Productivity Crisis*, Washington DC: Brookings Institution.

Chakrabarti, Alok K., 1988, 'Trends in Innovation and Productivity: The Case of Chemical and Textile Industries in the U.S.', *R&D Management* **18** (2), 131—140.

Chakrabarti, Alok K., 1990a, 'Innovation and Productivity: The Case of Chemicals, Textiles and the Machine Tools Industries in the U.S.', *Research Policy* **19**(1), 1—13.

Chakrabarti, Alok K., 1990, 'Scientific Ouput of Small and Medium Size Firms in High Tech Industries', *IEEE Transactions on Engineering Management.*

Chakrabarti, Alok K., Stephen Feinman and William Fuentivilla, 1982, 'The Cross National Patterns of Industrial Innovations', *Columbia Journal of World Business* **17** (3), 33—39.

Edwards, Keith L. and Theodore J. Gordon, 1984, *Characterization of Innovations Introduced in to U.S. Market in 1982*, Washington DC: U.S. Small Business Administration, Contract No. SBA—6050—A—82.

Freeman, Christopher, 1974, *The Economics of Industrial Innovation*, London: Penguin Books.

Freeman, Christopher, 1971, *The Role of Small Firms in Innovation in the United Kingdom Since 1945. Report to the Bolton Committee of Inquiry on Small Firms*, Research Report No. 6, HMSO.

Glisman, Hans H. and Ernst Juergen Horn, 1988, 'Compara-

tive Invention Performance of Major Industrial Countries: Patterns and Explanations', *Management Science* **34** (10), 1169–1187.

Griliches, Zvi (ed.), 1984, *R&D, Patents and Productivity*, Chicago: University of Chicago Press.

Halperin, Michael R., 1986, *The Publication of U.S. Industrial Scientists: A Company and Industry Analysis*, PhD Dissertation Drexel University, Philadelphia.

Halperin, Michael R. and Alok K. Chakrabarti, 1987, 'Firm and Industry Characteristics Influencing Publications of Scientists in Large American Companies', *R&D Management* **17** (3).

Kamien, Morton I. and Nancy L. Schwartz, 1975, 'Market Structure and Innovation: A Survey', *Journal of Economic Literature* **13**, 1–37.

Lawrence, Robert Z., 1984, *Can America Compete?*, Washington DC: Brookings Institution.

Levin, Richard C., Wesley M. Cohen and David C. Mowery, 1985, 'Appropriability, Opportunity, and Market Structure: New Evidence on Some Schumpeterian Hypothesis', *American Economic Review* **75** (2), 20–24.

Pavitt, Keith L. R., Michael Robson, and Joe Townsend, 1987, 'The Size Distribution of Innovating Firms in the U.K. 1945–1983', *Journal of Industrial Economics* **35** (3), 297–316.

Peiz, Donald and Frank M. Andrews, 1976, *Scientists in Organizations: Productive Climate for Research and Development*, New York: Wiley.

President's Commission on Industrial Competitiveness, 1985, *Global Competition: New Reality*, Superintendent of Documents, Washington DC.

Price, D. De Solla, 1980, 'The Citation Cycle', in Belver C. Griffith (ed.), *Key Papers in Information Science White Plains*, NY: Knowledge Publications.

Rothwell, Roy and Walter Zegveld, 1982, *Innovation and the Small and Medium Sized Firm*, London: Francis Pinter.

Scherer, Frederick M., 1965, 'Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions', *American Economic Review* **55** (5), 1097–1125.

Soete, Luc L. G., 1979a, 'The Measurement of Inventive Activity and the Firm Size', paper prepared for The Sixth EARIE Conference, Paris, September 9–12.

Soete, Luc L. G., 1979b, 'Firm Size and Inventive Activity: The Evidence Reconsidered', *European Economic Review* **12**, 319–340.