Innovation, Firm Size, and Firm Age

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ABSTRACT. This paper uses a new data set on innovation output to assess the degree to which the level of innovation in manufacturing firms is influenced by firm size and firm age. Indicators of innovation output used are the number of new products introduced as a function of firm sales and the proportion of firm sales obtained from products first introduced in the previous five years. While the evidence is mixed, the results tend to indicate that it is possible to separate the effects of age and size in assessing the level of innovation. Both firm size and firm age tend to be inversely related to innovative output.

1. Introduction

Over the past two decades a range of studies have attempted to specify the nature of the relationship between industrial firm size and the level of innovation. This paper takes a new look at the issue of firm size and innovation using a new data set developed on behalf of the National Science Foundation (NSF). In particular, using indicators of the level of innovative output of firms, it attempts to sort out the degree to which small firms appear more innovative than large firms because they are small, as distinct from the degree to which they appear to be more innovative simply because the small firms themselves are new. It also attempts abstract this analysis from issues such as R&D intensity, and industry type.

In his 1952 book *American Capitalism*, Galbraith advanced the idea that technological innovation was no longer the domain of individual innovators and, by extension, no longer an activity relevant to small business (Galbraith, 1952). Many viewed Galbraith's hypothesis as an extension of the Schumpeterian notion that static economic efficiency was a barrier to innovation because only through the accumulation of monopoly profits could innovation be financed (Schumpeter, 1942).

Fifteen years later, Nelson, Peck and Kalacek (1967) re-examined the Galbraith thesis using National Science Foundation (NSF) data on research and development (R&D) expenditures by industry. They found that up to the 1000 employee level there was a disproportionate increase in R&D spending with increases in firm size. These economies of scale did not extend above the 1000 employee level, however.

Studies that analyze factors such as R&D spending or the employment of research scientists and engineers, while offering pioneering insights into the importance of R&D in innovation (see, for example, Mansfield, 1968), have been criticized because they focus only on inputs to the innovation process, not outputs. Firms that devote relatively larger quantities of resources to innovation may actually be less innovative if they are not as efficient at converting those resources into commercialized innovations. A second problem with the R&D input approach is that some firms may not be able to report resources devoted to innovation separately from resources devoted to other functions within the firm. If a portion of the company president's time is devoted to innovation, for example, it is unlikely that a portion of his or her salary will be counted in the R&D spending category. This problem is most likely to occur in small firms. Thus it is suspected that small firms systematically underreport their levels of R&D.

In response to the perceived deficiencies in studies that focus on innovation inputs, a number of researchers have attempted to measure innovative output. Initially, these studies were based on courts of specific innovations. Each innovation was then traced back to the firm that developed it. Early studies of this type include Project Sappho (SPRU, 1972), a study by Kleiman (1975), and the first of the Gelman Studies (1976). More recent studies of this type include the continuing work of

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Townsend and his associates at the University of Sussex Science Policy Research Unit in Britain (1981), as well as that of DeBresson (1984) in Canada, the second Gelman study (1982) and that of the Futures Group (1984). Additional analysis based on this type of data can be found in Acs and Audretsch (1987, 1988).

A second approach to innovation output indicators has been to use the firm as the unit of analysis rather than the innovation. In these studies firms are asked about resources devoted to innovation at several stages of the innovation process and about the outcomes obtained. One of the advantages of this approach is that it inherently collects data on firm failures as well as their innovative successes. Studies of this type were pioneered by Scholz and Schmalholz (1982) in Germany and by Hill, Hansen and Stein (1983) in the U.S. on behalf of the NSF.

Virtually every study of innovation indicators that has been performed, both in the U.S. and abroad, shows innovation to be a much more widespread phenomena than indicated in the official statistics. DeBresson's study (1984) in Canada puts the point rather bluntly: "Until recently the common assumption about industrial innovation in Canada was very simple: there was none." DeBresson then went on to identify almost 2000 innovations that had somehow eluded the experts. Piatier and Burtschy's (1984) study of French innovation conducted in-person interviews with some 300 firms, none of which were included in the government's R&D statistics. They found that over half of these small and medium sized firms had organized R&D activities despite the fact that they had eluded government data collectors. Alfred Kleinknecht (1986), in a study of some 2900 Dutch manufacturing firms found that there were a large number of firms that perform R&D that have no formal R&D department. Several studies sponsored by the U.S. Small Business Administration also found that small firms disproportionately contributed to industrial innovation (Gelman, 1976; Gelman, 1982; Futures Group, 1984).

The question of firm size and innovative output has been especially difficult because innovation is inherently a multidimensional concept that cannot be measured by a one dimensional instrument. Innovation occurs in many forms and comprises many different stages or processes. Even if it were possible to accurately measure the number of innovations or innovative events or activities that occurred, it would still be necessary to account for the fact that some innovations have a much smaller impact on economic performance or social welfare than do others. As a result it has been recognized for some time that the optimal approach to assessing the level of industrial innovation is to collect a variety of pieces of information, none of which actually measures innovation, but all of which provide indicators of the level of innovation. According to Arnow (1980), indicators provide clues to underlying phenomena or relationships without providing precise measures of those relationships or phenomena. For example, the Gross National Product is an indicator of the health of the economy but it does not actually measure economic performance since economic performance is a complex phenomena, as is innovation.

2. Data set description

The U.S. National Science Foundation has been at the forefront of innovation data collection efforts in the United States. Some of the early work on the relationship between innovation and firm size was based on NSF data on R&D spending and scientific and engineering employment. Since 1981 the NSF has been funding an effort to develop new indicators of industrial innovation; indicators that went beyond the traditional measures of innovation inputs to attempt to assess the level of innovation output. The idea was to create a questionnaire that could be administered to a large number of firms (rather than those in specific industry) but would ask questions that relate to the phases of the innovation process other than R&D. In addition, the survey was to include questions about the environment in which R&D was conducted within the firm. The "environment" questions were included because previous research had shown that the environment in which R&D was conducted had a significant impact on the efficiency with which R&D resources are converted to commercially successful new products and processes (Allen, *et al.*, 1975; Von Hipple, 1978).

The questionnaire was sent to 2300 firms in 1986 to collect 1985 data (Audits and Surveys, Inc., 1987). The company that conducted the survey later determined that 515 surveys were sent to companies erroneously. Responses were obtained from 637 companies of which 598 are usable for the firm size and age analysis. The NSF data collection effort was not specifically designed to assess the differences in innovation between large and small firms; the questionnaire was not designed with this in mind and the sample was not drawn to achieve this goal. Nonetheless, the data set did turn out to yield some useful information in this area.

Two of the indicators contained in this data set are used to provide indications of the level of innovation in firms. The first was the number of new products introduced by the firm during 1985. Defining the concept "new product" is inherently very difficult. First, there is a difference between a product that is new for the firm, new for the industry, new for the country or new for the world. There is also a question of how radical a change is required to justify the appellation "new". It is important to attempt to exclude simple design changes (such as new color of soap) and changes in small components (such as a new cigarette lighter in an automobile). While it is recognized that this problem is probably unsolvable, some guidance was provided for firms in determining whether a product is new:

> A new product is one newly produced by your firm whose features, performance or cost is substantially different from your earlier products. A product might be considered "new" for example, if it is based on a firm's commercialization of a patent, or if it is the result of a separately identified design or development program.

The second indicator of innovation output in this data set was generated by a question that asked firms to estimate the percentage of sales in 1985 that resulted from products that were first introduced in the previous five years. This question was a useful addition to the first question for three reasons. First, interviews with firms seemed to suggest that, particularly in large firms, it would be difficult to estimate the number of the firm's new products because often no one individual or office was aware of all of the new products. This might result in an apparent bias in favor of large firms appearing to be less innovative than they actually are. Secondly, by asking about sales from new products it is possible to obtain some measure of the significance of the new products to the company. Finally, interviews with potential respondents indicated that more and more companies were collecting this information about themselves for strategic purposes.

Data on firm size was collected from firms on the questionnaire itself both on the basis of domestic employment and domestic sales. In order to assess the impact of firm age, however, it was necessary to add data on when each firm began operations. For the publicly-held companies this was relatively easy since they were generally listed in Moody's Industrial manuals or other readily available sources. For privately-held firms considerably more work was required, but ultimately the information was obtained for 598 companies.

The term "began operations" is somewhat vague. A wide range of dates could be used for this variable including the date of founding, the date of incorporation, the date of acquisition (in the case of a firm whose current incarnation came about through merger), the date of introduction of the now dominant product line, etc. As a result, a significant amount of judgment was required in interpreting the history of the firm as detailed in sources such as Moody's. The goal of the age variable was to assess how long the firm had been in business. In most cases the date of founding was used. In some cases all that was available was the date of incorporation. In yet other cases, where a firm was "founded" through the merger of two other companies in the same line of business, yet another date had to be used. While some judgment was needed in constructing this variable, in general alternative judgments would not have resulted in substantially different data. In most instances these judgments were made in the case of older companies. We were left to decide whether say, 1895 was a more appropriate date for a specific firm than 1910. It seems unlikely that such decisions could substantially effect the quantitative results obtained.

In addition to data on firm age and firm size a number of other factors were included. Some industries, for example, provide greater opportunities for innovation than others. This was accounted for in two ways. In some instances it made sense to use a dummy variable for firms in industries with particularly high levels of innovation. The ratio of R&D expenditures to sales was also sometimes included to account for this.

Both of the output indicators are related to new products introduced by the firm, not new production processes. Attempts had been made to formulate questions that would gather information about the level of process innovation in firms, but these efforts were universally unsuccessful. As a result it was important to include a question that asked firms to specify the proportion of R&D funds that were spent on product innovation rather than process innovation since one would expect that firms that devoted a larger portion of their resources to product innovation might appear more "innovative" given that the indicators focused on new product outcomes.

Universities are important sources of innovative work for industrial firms. In addition to conducting basic and applied research of interest to industry, universities can provide technical expertise to industry in the form of faculty consultants or advisors. Universities also serve as a valuable mechanism for codifying and disseminating the results of research performed elsewhere. In addition, the existence of relationships between firms and universities shows a degree of openness to ideas from sources outside the firm. A variety of research results that demonstrate the importance of university-industry interactions were reviewed by Mogee (1980). The TRACES study, for example, found that 60 percent of the R&D events leading to technological developments occurred in universities. Thus, relationships with universities might be one factor that would make a firm's internal R&D more efficient in producing new products.

Short term R&D projects may be more likely to be tied to specific currently-identifiable market needs than long term projects. Data on project length, therefore, was included in the questionnaire to provide a means of evaluating Von Hipple's contention that research driven by market needs results in more commercial successes than other research.

3. Model 1: The number of new products

The first output indicator used was the number of new products introduced by the firm in 1985 per $10 million in domestic sales. The regression results are provided in Table I. The date of founding of the company is, as expected, positively related to the number of new products (implying that firm age and new products are inversely related). The second variable is domestic employment in thousands of employees and represents a measure of firm size. In this model, smaller firms do produce more new products per $10 million in firm sales than do larger firms *even after controlling for the effect of firm age*. What's more if either the age or the size of the firm is dropped from the model (Table II) there is very little change in the remaining coefficient or T-statistic. This implies that the regression equation is really picking up a difference between the effect of size and age.

The chemical industry introduces an abnormally large number of new products in the form of new chemical compounds each year. As a results, a dummy variable corresponding to firms in SIC category 28 was included. It is significant with the expected sign. Finally, as expected, when firms devote more of their R&D dollars to product

TABLE I
Innovation Model 1: New products (1985) per $10 million in domestic sales

RHS variable	Coefficient	Standardized coefficient	T-statistic	Significance level
Constant	−12.416	0.0	−2.05	96%
Year firm began operations	0.006	0.106	2.08	97%
Domestic employment (000)	−0.011	−0.104	−2.07	96%
Percent of R&D for new products	0.008	0.130	2.62	99%
Chemical industry	0.424	0.262	1.62	90%
Multiple correlation (R) = 0.225				

TABLE II
Analysis of multicollinearity between firm size and firm age Model 1

	Full model		Drop firm size		Drop year began	
	Coef.	T-stat.	Coef.	T-stat.	Coef.	T-stat.
Constant	−12.416	−2.05	−15.072	−2.54	0.331	1.39
Year began	0.006	2.08	0.008	2.54	–	–
Dom. empl.	−0.011	−2.07	–	–	−0.015	−2.75
Chem ind.	0.424	1.62	0.418	1.59	0.376	1.44
% R&D for new prod.	0.008	2.62	0.009	2.67	0.007	2.04

rather than process innovation, they produce more new products.

The other variables (R&D intensity, etc.) show no relationship to the number of new products introduced. This may well be because the data set is not sufficiently robust to pick up these effects.

4. Model 2: Sales due to new products

Firms seem to be more comfortable answering the question about the proportion of 1985 sales that resulted from products first introduced in the previous 5 years than they do about answering the number of new products question. At first blush this may appear to be a paradox, since it would seem that knowing which products are new would be a necessary condition for knowing that proportion of sales is accounted for by those products. As it turns out, however, this is not the case. On the questionnaire firms were asked to make *estimates* of these values if they did not keep records of them for their own internal purposes. Most respondents felt that they were capable of making a reasoned estimate of the sales due to new products even when they had a difficult time identifying the number of new products.

Table III shows the regression analysis that resulted from using the sales due to new products output indicator. Firm age is again represented by the year the firm began operations and is positively related to sales from new products. Thus newer firms have higher sales percentages from new products than do older firms. Domestic employment is again used as a measure of firm size. The variable shows the expected sign (small firms have higher sales from new products) but is only significant at the 70% confidence level. In addition the impact of this variable is small compared with the other variables in the model.

The fact that this variable is significant in the first model and not in the second may be due to either of two possible explanations. First, it may be

TABLE III
Innovation Model 2: 1985 sales attributable to products introduced in 1981–1984

RHS variable	Coefficient	Standardized coefficient	T-statistic	Significance level
Constant	−525.84	0.0	−5.95	99%
Year firm began operations	0.28	0.27	6.10	99%
Domestic employment (000)	−0.07	−0.04	−1.02	70%
Percent of R&D for new products	0.16	0.15	3.37	99%
R&D to sales ratio	0.96	0.21	4.83	99%
SIC 35, 36 or 38	10.86	2.76	3.93	99%
% R&D in long term projects	−0.12	−0.13	−3.11	99%
Grants to universities	0.02	0.10	2.34	98%
Multiple correlation (R) = 0.565				

that there is a tendency for large firms to underreport the number of new products that they produce if the individual who fills out the survey form is not aware of the number of products in those parts of the company that are distant from his own. Alternatively, it may be that since new firms *must* have higher sales from new products (any firm founded in the 1980s, for example, will have 100 percent of its sales from new products), the effect of age simply swamps the effect of size in this model. To attempt to test this proposition this regression was also run using only the firms that were founded before 1980. This brought up the significance of the size variable somewhat, but it still failed conventional significance tests.

Further evidence for the interdependence of size and age in this instance are found in Table IV, which presents an analysis of the multicollinearity of size and age. By and large the coefficients change very little when either the size or age variable is dropped. One exception is that when firm age is dropped the coefficient on firm size more than doubles and becomes more significant. This provides an argument for leaving firm size in the model despite its relatively low T-statistic. Clearly in this model some of the effects of firm size are being captured in the age variable. The results of this model are consistent with the findings of the previous model — that both new firms and small firms rate higher on these output indicators than do large or old firms, but that the interaction between the size and age variables, while small (−0.23), muddies the waters a bit in this case.

The other variables in the model are of the expected sign and are significant. The standardized coefficient column in Table III, which shows the relative magnitude of the effect of each of the explanatory variables, indicates that the inter-industry differences are much more significant than those of any other variable.

5. Summary and conclusions

The new data collected under the auspices of the National Science Foundation confirm what was previously known about innovation in small firms: Small firms do innovate and their contribution to innovation is considerably understated by the R&D data and other input indicators. In the first innovation model presented in this paper, it was found that both firm size and firm age are significant determinants of the number of new products produced per dollar of sales. Not surprisingly, it was also found that the higher the proportion of R&D resources devoted to product rather than process R&D, the more new products were in fact produced.

The second model explained the percentage of sales resulting from recently introduced products. In this model it is more difficult to separate the effects of firm age and firm size but the signs of the coefficients were consistent with those of the first model. The second model also showed that the amount of sales from new products was positively related to the proportion of R&D devoted to product rather than process innovation, research grants to universities, R&D intensity, and whether the firms main output was in SIC categories 35, 36, 38 or in some other SIC group. Sales from new

TABLE IV
Analysis of multicollinearity between firm size and firm age Model 2

	Full model		Drop firm size		Drop year began	
	Coef.	T-stat.	Coef.	T-stat.	Coef.	T-stat.
Constant	−525.84	−5.95	−544.32	−6.30	13.02	3.91
Year began	0.28	6.10	0.29	6.43	–	–
Dom. empl.	−0.07	−1.02	–	–	−0.16	−2.24
% R&D for new prod.	0.16	3.37	0.16	3.36	0.16	3.29
R&D to sales	0.96	4.83	0.95	4.78	1.16	5.71
SIC 35, 36, 38	10.86	3.93	11.09	4.03	11.90	4.25
% R&D long-term	−0.12	−3.11	−0.17	−3.21	−0.12	−3.11
Univ. grants	0.02	2.34	0.02	2.31	0.02	1.59

products also appears to be negatively related to the proportion of a firm's applied R&D budget devoted to projects running five years or more.

In designing policies to promote innovation it is critical to avoid confusing indicators with policy instruments. For example, scores on the SAT exam and other standardized tests are often used as an indicator of the performance of public schools in the U.S. It does not follow, however, that any method of improving SAT scores will necessarily improve the quality of public school education. The quickest way to improve the standardized test scores would be to pass out copies of the answers before the examination but this would hardly result in an improvement in the educational system.

So it is with innovation indicators. They do not measure innovation, they are merely indicators of innovation. Data which serves as the basis for a good indicator may not necessarily also constitute an appropriate policy instrument. For example, for a very long time one of the best innovation indicators available was R&D spending. However, R&D spending is not a measure of innovation, it is only an indicator. Policies simply designed to increase R&D, rather than innovation, often did not live up to expectations. R&D tax credits, for example, may have resulted in increased innovation, but many of the firms surveyed in the course of collecting the data for the early phases of this study said that the R&D tax credit merely caused them to "discover" R&D activities that they had been doing all along, but had not been reported as R&D.

Similarly, the numbers of new products and their sales are merely indicators of innovative output. If we develop policies to specifically encourage these activities it may not result in higher levels of innovation, but instead it may simply result in firms producing a myriad of variations on existing products. Furthermore, if small firms have levels of new product output that are as high or higher than large firms, it does not necessarily follow that encouraging the development of small firms in general will necessarily result in higher levels of innovation. If those funds are swallowed up by small firms that are not innovative (grocery stores, gas stations or fragmented manufacturing concerns where it is impossible to appropriate the benefits of innovative activities) then it is highly unlikely that increased innovation will result. While indicators are indispensable tools for learning more about the extent and nature of innovation, they are no substitute for analysis of the effects of specific policy proposals.

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