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Analysis of Firm Size Effect on R&D Activities in Japan[1]

By
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Abstract

In this paper we examine the effect of firm size on R&D activities using regression analysis. We choose 377 firms from 6 industries to show both intra-industry and inter-industry differences in R&D activities. Our results reveal that (1) firm size explains a large part of the differences in R&D spending levels, (2) we cannot easily decide the functional form representing firm size-R&D relationship because a few large firms influence the model significantly, and (3) firm-specific and industry-specific variables, representing the state of technology, should be considered in the future.

1. Introduction

In the past few decades, a considerable number of studies devoted to the analysis on the relationship between firm size and the level of R&D expenditure, have suggested that large firms would have the advantage over relatively small firms in R&D activities. In fact, we can observe intra-industry differences in R&D intensity, which is generally used as the measure of R&D performance. Cohen and Klepper (1992) have taken some important steps in this direction, examining the pattern of R&D intensity distributions at the SIC two-digit level using the individual FTC lines of business data. They tried to deduce a probabilistic model of R&D in order to account for the distributional regularities. Their conclusion returns to the long discussed matter: the effects of firm size on R&D and innovation. Numerous attempts to solve this problem, however, use rather old data of the 1960s and the 1970s. This urgently calls for an examination with recent data on how firm size plays an important role in conducting R&D. To begin with, we review the previous studies and indicate what problems still remain. Next, after presenting the characteristics of our sample data used in this paper, a comparison of the firm size and the R&D intensity distributions between industries is provided. Following the presentation of the model and its estimation results, some remaining issues are discussed at the end of the paper.

2. Analytical Viewpoints in the Previous Studies

Mansfield (1963) noticed about 30 years ago that there is a critical investment level required for innovation, and found that the four largest companies made up a large share of the innovations. He also pointed out in his successive work (1964), which examined the data of 38 firms in 5 industries from the period 1945 to 1959, that firm size is one of the determinants of R&D expenditure level. This issue on the relationships between firm size and R&D expenditure has led to the discussion on how market concentration affects R&D performance. Although concentration has been a topic of study for a long time, there is little agreement to the degree which it is desirable for the maximization of R&D activities[2].

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[1] I wish to express my gratitude to the anonymous referee for valuable comments and criticisms.
[2] For more details about the theoretical framework, see Kamien and Schwarts (1976), Loury (1979), and Dasgupta and Stiglits (1980).

Without definite results from empirical analyses during the 1980s, firm size, however, is still believed to be a determinant of R&D level. One of the exceptional approaches is made by Pakes and Schankerman (1984), which refers to the appropriability of R&D outcome and the technological opportunities[3] corresponding firms face. They admit the limit of their model and data because both appropriability and technological opportunity are unobservable and they cannot separate the contribution of these two factors on intra- and interindustry differences in R&D intensity. In the late 1980s, researchers seemed to be mixed up in choosing independent variables in their models[4].

Although the differences in innovative activities are believed to be caused by the joint effect of factors relating to production and R&D, what those analyses tried to reveal was ambiguous. Cohen, Levin and Mowery (1987), however, indicate that both business unit and firm size do not explain the variance of R&D intensity, and that what influences this variance is industrial effect: differences in technological opportunity, appropriability and market condition. Again, it was their failure to confirm the effect of firm size that have driven them to depend on these troublesome variables. There is one further problem that we must not ignore. Most of the works during the 1980s are based on 1970s data, when many developed countries experienced structural changes. For this reason, results of those analyses cannot be accepted as decisive conclusion. Several articles have analyzed this subject in Japan since more than a decade ago using similar approaches. For example, Nakanishi et al. (1983) deduces that industrial concentration has a negative effect on R&D performance. Another work by Doi (1977), however, shows that four-firm concentration does not have a significant effect but firm size does at 1% level. Uekusa (1982) concludes that R&D expenditure level increases as firm size becomes larger until firm size reaches some critical points. He classifies industries into three categories: innovative, average, and maturing. He also suggests that it is the larger firms in innovative industries that have the advantage over smaller firms. There is sufficient evidence to show that, in Japan, firms with larger capital, more employees, and larger sales spend more R&D expenditure than "smaller" firms. Nakajo (1994) has examined R&D concentration on large firms using data from the Survey of Research and Development by the Statistics Bureau at the Management and Coordination Agency. R&D expenditures of the top 5 companies in an industry are found to account for more than 50% of total industry expenditures in 16 industries. Compared with sales concentration in the top 5 firms, R&D concentration is distinctly observed in more industries. Although Uekusa (1982) deduced the foregoing conclusion based on 1960s' data, our data may also show similar results that large size is conducive to innovative performance. Since data at the industry level are only available from the Survey of Research and Development, we have to use individual firm's R&D data in its financial statement. Unfortunately, however, not all companies report their R&D spending as there is no legal obligation to announce it. Even when R&D expenditures are reported, R&D expenditures are sometimes entered as different items of the account as to different firms. Moreover, there are some companies which declare their R&D spending intermittently and this does not allow us to perform time series analysis.

3. Data

In this paper, the sample firms are chosen from 6 industries: textiles, iron and steel, general machinery, transport equipment, electrical machinery, and precision instruments[5]. Firms which

[3] According to Scherer (1965), technological opportunity indicates animation of "scientific climate" and possibility that new technology appears.

[4] For example, Acs and Audretsch (1988) select eight independent variables, including one regarding labor union, to show how these inputs are transformed into innovative outputs.

[5] Chemical industry accounts for above 15% of R&D expenditure in Japan, but they are excluded from the sample. This industry includes chemical fiber, oil and paint, drugs and medicines, and other chemical products, all of which are quite different from one and another in terms of technology. Technological heterogeneity in one

are not listed in the First Section at the Tokyo Stock Exchange in fiscal year 1993, and those which do not report R&D expenditure of the corresponding year are excluded from this sample[6].

In the end, 29 out of 46 firms (63%) in textiles, 22 out of 38 firms (58%) in iron and steel, 66 out of 96 firms (69%) in general machinery, 34 out of 56 firms (61%) in transport equipment, 83 out of 121 firms (69%) in electrical machinery, and 15 out of 21 firms (71%) in precision instruments remain. We found that about 30% or 40% of these firms, an unexpectedly large portion of the whole, do not earmark R&D expenditures. Compared with data of the Survey of Research and Development by the Statistics Bureau at the Management and Coordination Agency, however, R&D by firms in this sample represents on average 55% of the corresponding industrial R&D ·. The sample size is reduced considerably, including 250 firms in all. This is unavoidable due to the limitation of data because we can neither ascertain the reason why each firm does not report its R&D expenditure nor estimate it directly from its financial statement. R&D expenditure data of individual firms are also reported in other sources such as *Kaisha Shikiho* (Firm Quarterly Report). More firms announced their respective R&D expenditures in *Kaisha Shikiho* than in financial statement, but for some unknown reasons, R&D expenditure reported in *Kaisha Shikiho* is usually larger than that in financial statement (generally 2 or 5 times to 181 times at maximum). In this paper, R&D expenditure data are taken from financial statement because sales data are also taken from financial statement in this paper. As a matter of fact, sales data in *Kaisha Shikiho* are also quoted from financial statement. It is important to bear in mind that since the listed companies meet the requirements of listing, they are firms beyond certain "size". According to the listing standard, they are required to reach certain levels in terms of (1)the number of listed stocks, (2) the number of stockholders, (3) the number of years they do business continuously, (4) net assets, (5) annual net profit, and (6) dividend (under Article 7, Clause 1 and 2, Article 13 of the Listing Agreement). In other words, the firms we examine rank high in terms of sales or profits in their respective industries. Our analysis are still important, however, because there are some vital differences in their R&D activities even among relatively large firms. To begin with, we represent the distribution of firm size (measures in terms of sales) by industry, including the firms with no R&D reports (Figure 1). The black bars in the histograms indicate the number of the firms excluded from our sample. It should be noted that the scales of the horizontal axis are different among the industries.

As Figure 1 shows, the solid black bars clustered at the left hand side of the histograms. This means that relatively small firms tend not to disclose their R&D activities. Although this data restriction has been pointed out in various studies, our analysis cannot but be biased toward larger firms.

One exception is the case of transport equipment industry (Figure 1-d). Most of the world famous auto-makers with large sales compared with other companies do not report their R&D spending level[7]. In addition, we also cannot obtain the R&D data of several other firms with relatively large sales. These companies definitely consider R&D activities as important and must have spent a certain amount of R&D expenditures. If they had declared their R&D spending, we could have deduce more precise explanation about size effect on R&D performance in the transport equipment industry.

industry should be discussed at more disaggregated level in the future.

[6] We also exclude firms which (1)consign research to other firms or institutions and report that expenses as general and administrative expenses, (2) report R&D expenditures not as general and administrative expenses but as research depreciation included in non-operating expenses, (3) report R&D as research depreciation of deferred assets in balance sheet, and (4) report spending on experiment tools (which are presumably R&D-related but cannot be identified exactly).

[7] In fact, this happens not only for 1993 but every year, hence we cannot made estimation by using the previous year data.

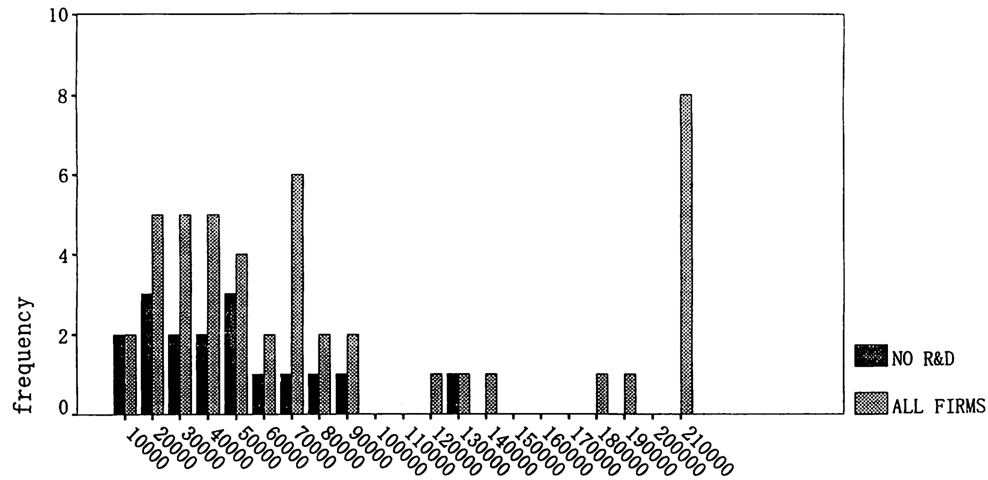

Figure 1-a: Firm Size Distribution
Textiles

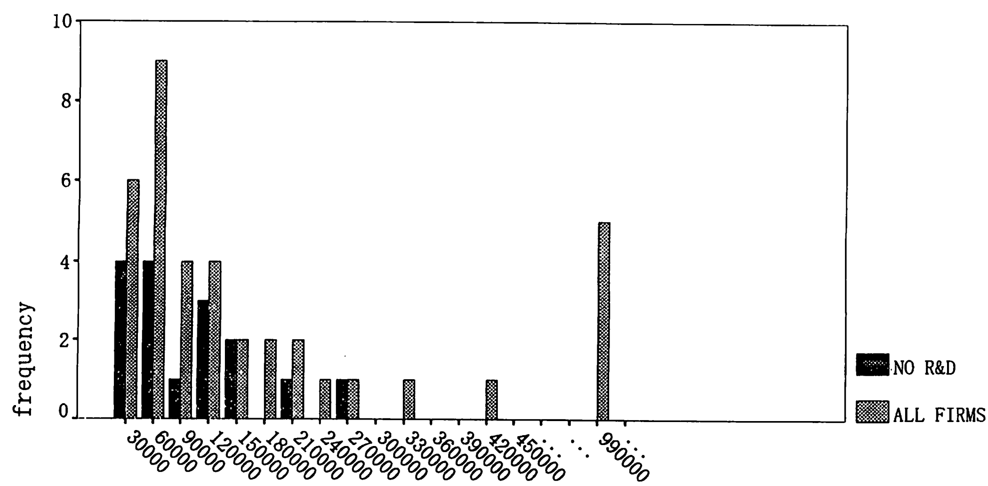

Figure 1-b: Firm Size Distribution
Iron and Steel

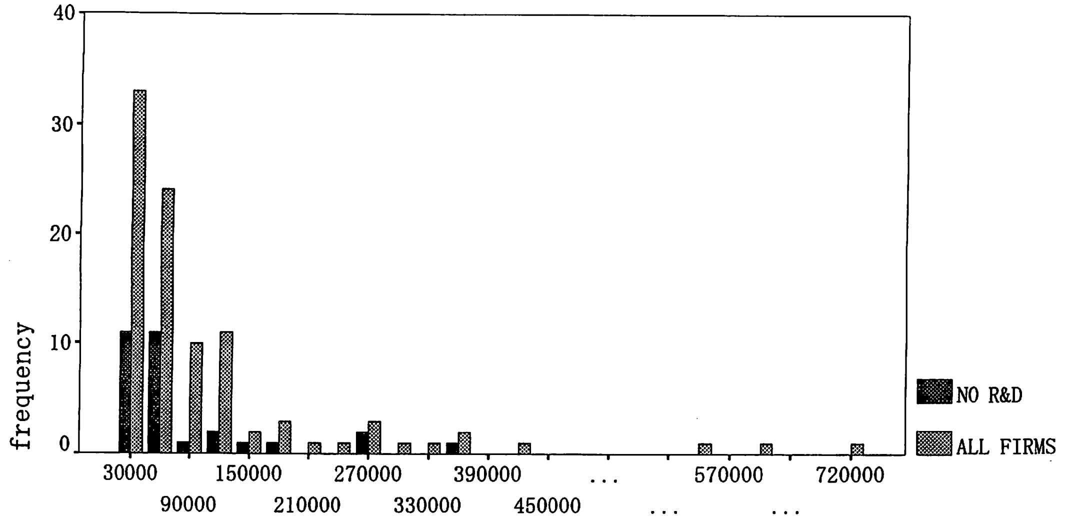

Figure 1-c: Firm Size Distribution
General Machinery

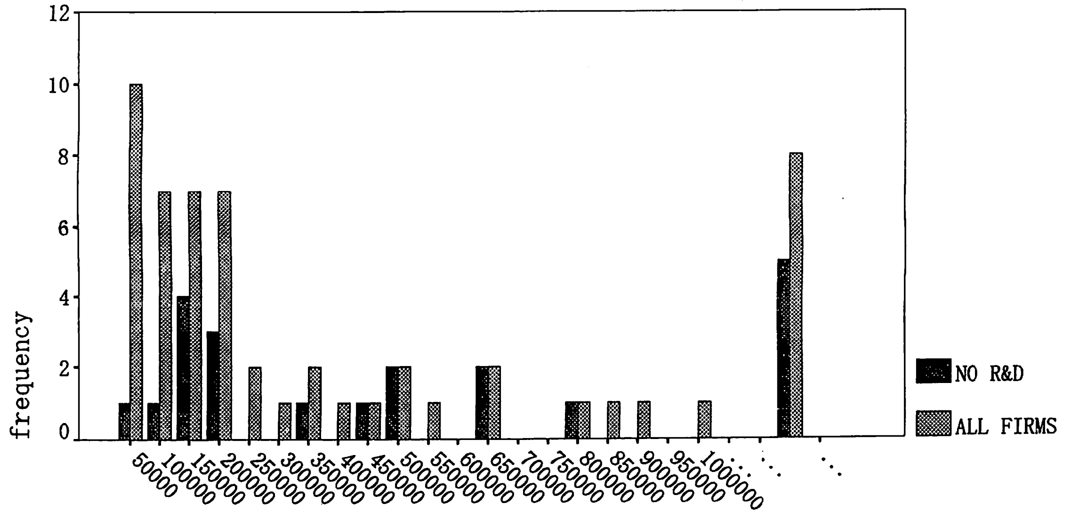

Figure 1-d: Firm Size Distribution
Transport Equipment

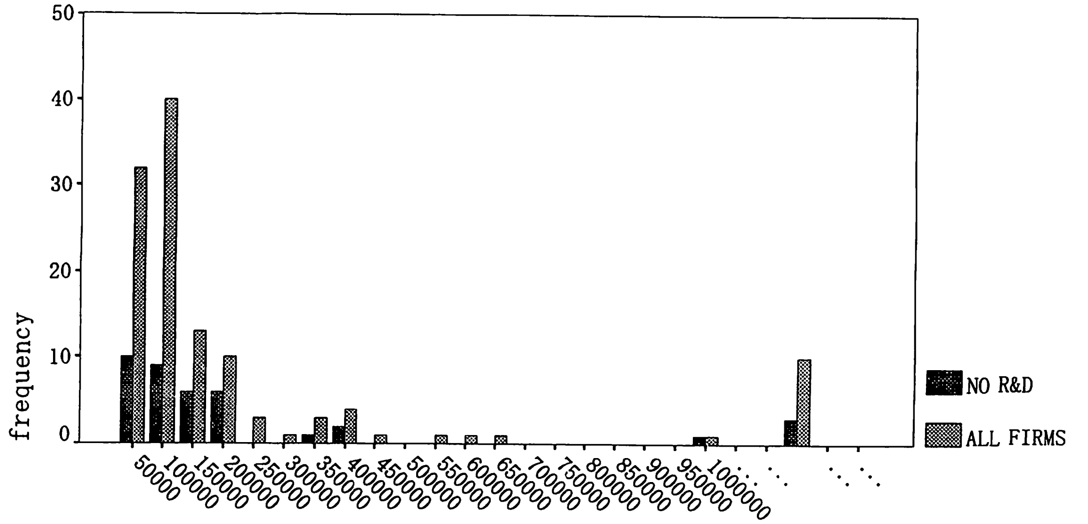

Figure 1-e: Firm Size Distribution
Electrical Machinery

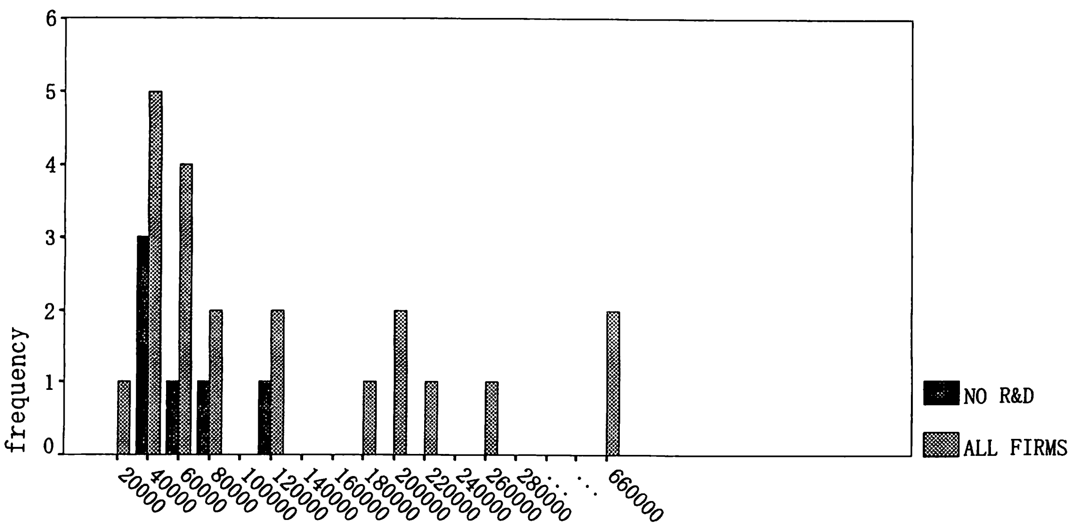

Figure 1-f: Firm Size Distribution
Precision Instruments

Table 1: Descriptive Statistics on Firm Sales, R&D Expenditures, and R&D Intensity by Industry

Industry	Sales(million yen)				R&D Expenditures (million yen)		R&D Intensity (%)	
	All Companies		Sample					
	min.	max.	min.	max.	min.	max.	min.	max.
Textiles	2248	994488	16829	994488	25	38999	0.08	5.30
Iron & Steel	8596	2368853	15489	2368853	64	35265	0.06	2.79
General Machinery	9198	748593	9198	748593	7	27161	0.03	7.15
Transport Equipment	23995	9030857	23995	2615959	20	64186	0.03	3.32
Electric Machinery	9724	4550086	13342	3811498	70	319278	0.14	13.32
Precision Instruments	16297	1036938	16297	1036938	111	118282	0.24	11.41

Table 1 summarizes the range of firm sales, R&D expenditure, and R&D intensity (the ratio of R&D expenditures to sales) by industry. The differences between minimum and maximum R&D expenditure within the industry are extremely large. In general machinery, for example, the company with the maximum R&D expenditure spends about 4,000 times more than the one with the minimum R&D expenditure. The intraindustry variation in R&D activity is also reflected in the wide range of R&D intensity[8].

Some companies spend heavily on R&D activities, while others seem to regard them less important and/or are not able to spare enough budget for them. If minimum R&D level required for continuous and successful innovation activities does exist, as Mansfield mentioned long ago, the lower limit would reflect the marginal capacity of R&D performance.

Figure 2 also illustrates the R&D intensity distribution by industry. All the industries show similar pattern[9].

A substantial number of zero reports are excluded, as mentioned above. When converting this pattern into a prototypical frequency, we notice that R&D intensity in our sample can be classified into three groups. Group one consists of those whose intensity is less than 1. The second group is the one positioned at the middle. The last group contains the companies with high intensity and sometimes these companies are also the largest in their respective industries. That is, the largest firms are more innovating and may take a leadership in R&D performance. This frequency pattern we observed is different from the one examined by Cohen and Klepper (1992). The distributions in their paper are positively skewed with a tail to the right, and we can safely say that this feature is roughly the same as ours. They could not find, however, intra-industry groups classified in terms of R&D performance, which may be an important clue to explain the difference in R&D strategies among firms in the same industry.

[8] We can also observe the inter-industry differences in R&D intensity. This issue will be discussed in the later part of this paper.

[9] However, the pattern of the precision instruments industry presented in Figure 2-f is rather different from those in other industries, but this is largely due to the small sample size.

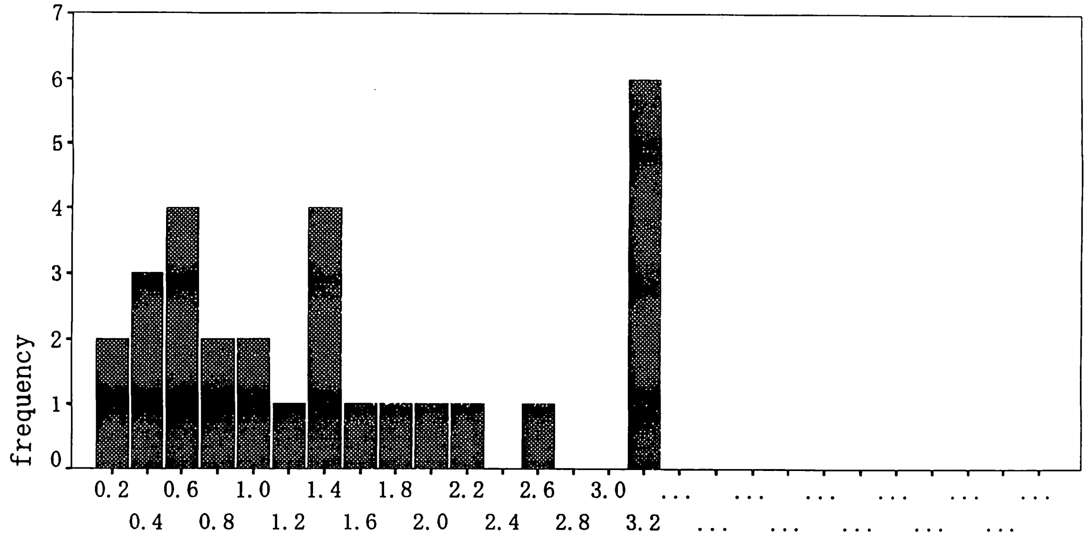

Figure 2-a: R&D Intensity Distribution
Textiles

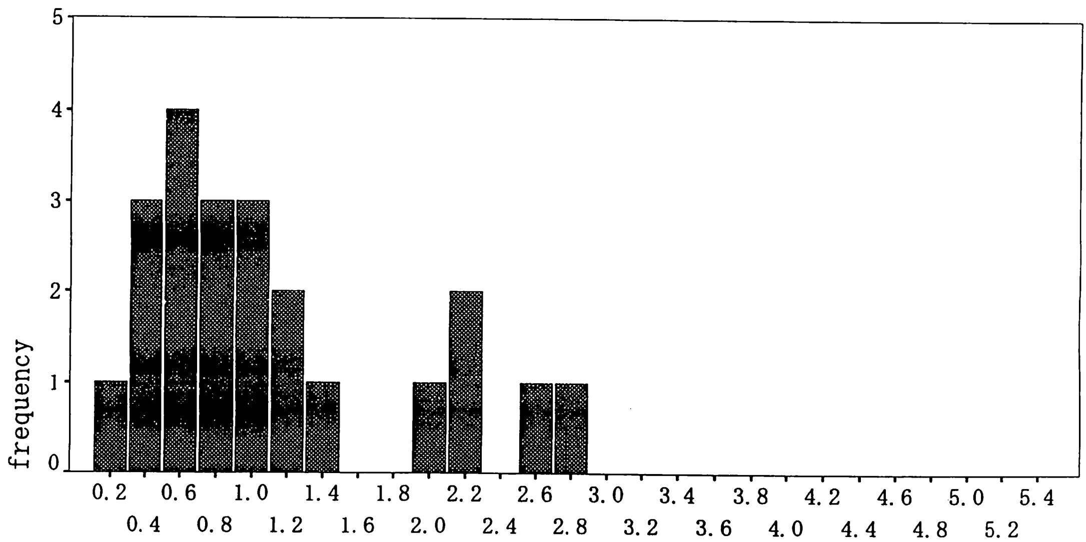

Figure 2-b: R&D Intensity Distribution
Iron and Steel

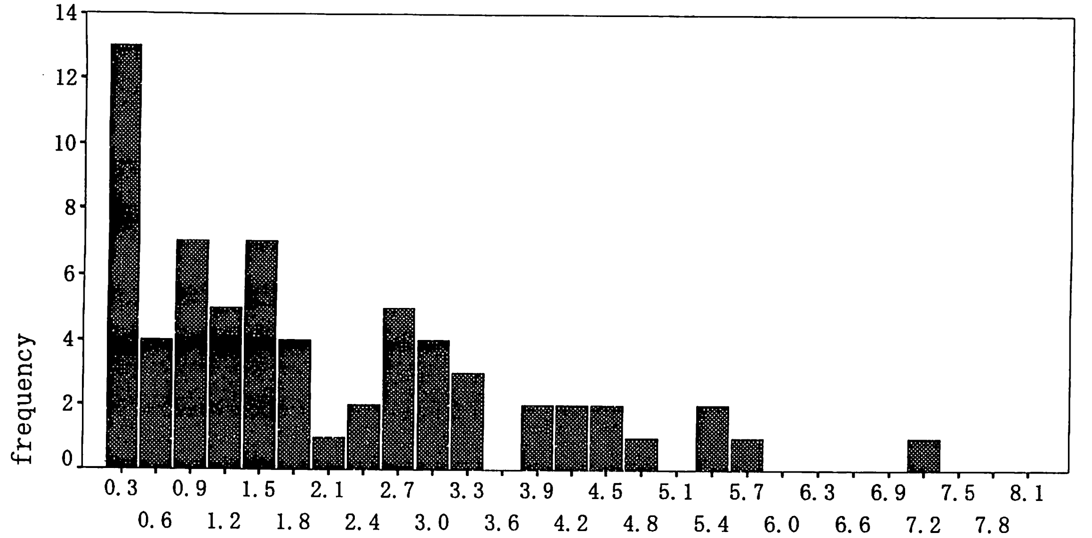

Figure 2-c: R&D Intensity Distribution
General Machinery

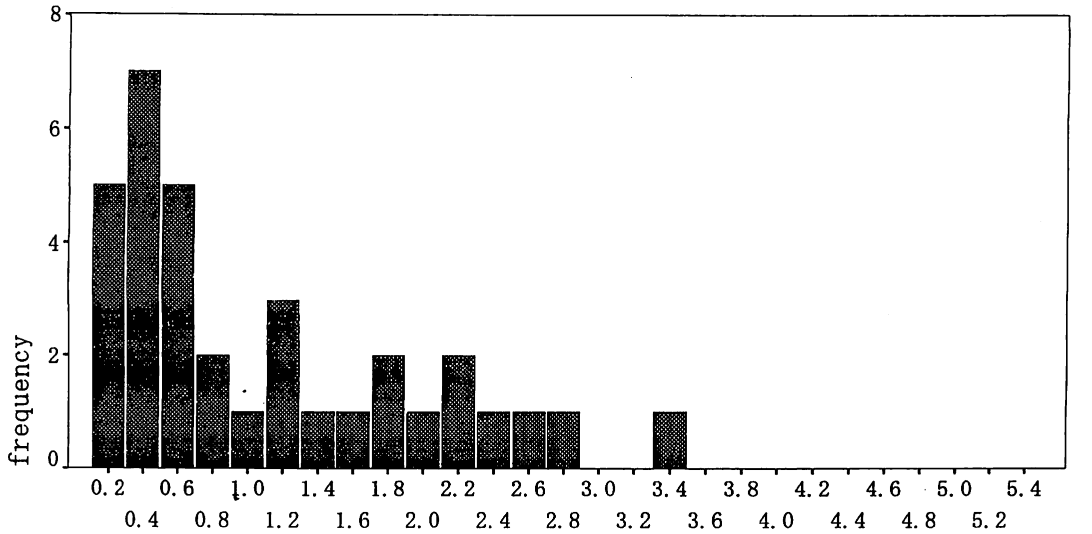

Figure 2-d: R&D Intensity Distribution
Transport Equipment

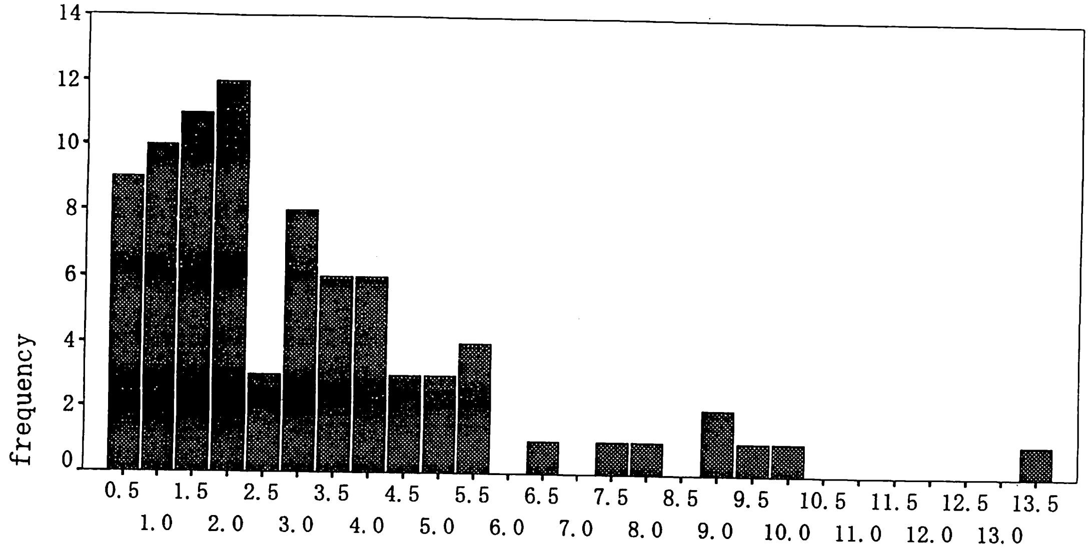

Figure 2-e: R&D Intensity Distribution
Electrical Machinery

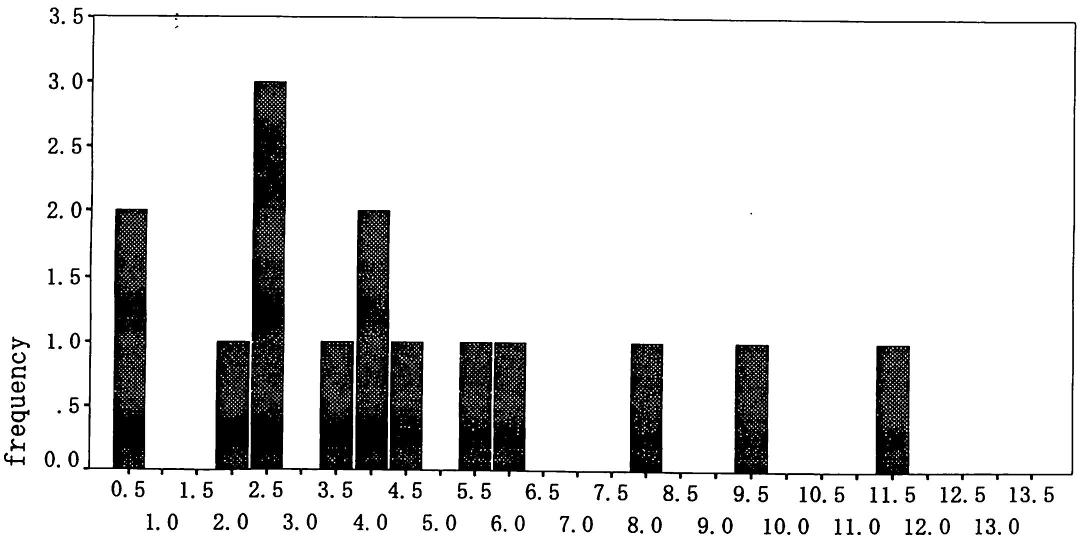

Figure 2-f: R&D Intensity Distribution
Precision Instruments

4. Regression Results and Implications

To examine the relationship between firm size and R&D activities, our model is specified as follows,

$$R = \alpha_0 + \alpha_1 S \tag{1}$$

$$\log R = \beta_0 + \beta_1 \log S \tag{2}$$

$$R = \gamma_0 + \gamma_1 S + \gamma_2 S^2 \tag{3}$$

where R is R&D expenditure, and S is sales, a proxy for firm size. We leave out functional forms representing the relationship between R&D intensity and firm size. Consider for instance the following function,

$$R/S = f(S) \tag{4}$$

As long as R&D intensity can be described as a ratio of R to S, Model (4) is just another form of Model (1). Hence, we examine (1) linear model, (2) logarithmic model, and (3) quadratic function model to decide which form is the most suitable[10].

The estimation results are shown in Table 2, and the number in the second column indicate the model used. Table 2 reveals that, all the six industries are better characterized by Model (1) and (3) than by Model (2). Surprisingly, Model (1) contains only one independent variable S and explains large part of the size-R&D relationship. Considering R^2 as the goodness of fit, could we choose between models (1) and (3) ? The main reason why the different models present nearly the same level of fit is that a few large size firms affect the functional form. When drawing size-R&D plots (not shown in this paper), we notice that relatively small firms in our sample are on linear lines, while a small number of large firms are rather off the lines. Hence, it is dangerous to conclude from our estimates that relationship between firm size and R&D activities is generally quadratic.

Our results lead to the conclusion that:

1. firm size is still the determinant of R&D spending level in Japan,
2. firm size-R&D relationships can be described as either linear or quadratic functional form, and
3. we may have missed what represent firm-specific and industry specific variables in these models.

[10] It is possible to deliberate the relationships between firm size expansion and R&D activity. This may reflect the idea that size increase will require more technological knowledge to be used as an input for production. Unfortunately, however, as far as our estimation period is concerned, firm's sales were generally declining and statistically significant estimates could not be obtained from the size expansion model. It is interesting to find that firms continue to spend money on R&D activity even when sales are declining. The R&D strategies of firms is, however, a question which I would not deal with in this paper.

Table 2: Estimation Results

Industry	Model	const.	S	$\log S$	S^2	R^2
Textiles	(1)	-1652.1	.0422			.870
		(-1.857)	(13.168)			
	(2)	-74990		7045.97		.636
		(-6.232)		(6.739)		
	(3)	-1906.5	.0453		-4.E-09	.870
		(-1.671)	(4.998)		(-.366)	
Iron & Steel	(1)	343.563	.0144			.695
		(.221)	(6.753)			
	(2)	-65772		6027.92		.675
		(-5.837)		(6.442)		
	(3)	-2671.2	.0355		-1.E-08	.882
		(-2.361)	(8.728)		(.)*	
General Machinery	(1)	667.785	.0116			.238
		(1.243)	(4.471)			
	(2)	-19196		1929.80		.278
		(-4.472)		(4.970)		
	(3)	-830.06	.0378		-4.E-08	.394
		(-1.363)	(5.473)		(.)	
Transport Equipment	(1)	-1608.7	.0215			.911
		(-1.888)	(18.053)			
	(2)	-92911		8325.28		.584
		(-6.242)		(6.706)		
	(3)	-1137.0	.0185		1.3E-09	.912
		(-1.081)	(4.519)		(.)	
Electric Machinery	(1)	-5640.4	.0754			.869
		(-2.201)	(23.217)			
	(2)	-363866		33138.2		.520
		(-8.867)		(9.374)		
	(3)	-3829.9	.0597		5.1E-09	.872
		(-1.313)	(4.746)		(.)	
Precision Instruments	(1)	-7343.8	.1095			.950
		(-3.085)	(15.657)			
	(2)	-207419		19252.5		.546
		(-3.666)		(3.958)		
	(3)	-76.924	.0289		8.2E-08	.989
		(-.048)	(2.254)		(6.516)	

Independent Variables: const., S, $\log S$, S^2

* we cannnot calculate t value in terms of these coefficients.

5. Further Discussion

Although the relationship between firm size and R&D expenditure is generally significant, we have to explain what causes intra-industry variation in R&D (why do the largest firm(s) spend on R&D more than proportionately) and inter-industry variation (why do textile and general machinery industries fit worse than others) in the future. Scott (1984) estimates the model which control both company and industry effects. It would be desirable to assume potentially that each company has its own R&D history and is conditioned by market and technological situation of its industry. Some researchers mention technological opportunities and market conditions (appropriability), but few of them succeed in dealing with these two characteristics. The term "technological opportunity" could be defined as closeness to science and/or industry maturity (Cohen, Levin, and Mowery (1987)). It is entirely conditioned on production but difficult to seize objectively using observable indices. By investigating how much an industry is close to science, we may break down technology which the industry adopts into technical elements[11] and examine the degree with which its technology is based on scientific fields. Furthermore, we must be careful in referring "industry maturity" as technological opportunity because maturity would be caused not only by the technology state but also by the demand condition. It would be better to exclude this demand side maturity[12] from technological opportunity. On the other hand, "appropriability" will be derived from competitive advantage in the market. Although it might be natural that appropriability is one of the determinants of R&D activity level, we may also need to consider the opposite causal relationship. Successful R&D performance, with new or improved technology, might lead to competitive advantage. The firm(s), owing to its (their) innovations, could enjoy profits from product differentiation at least as long as the lead time. If it is difficult for other firms to imitate the new (improved) product or process easily (that is, the lead time is very long), the innovative firm(s) will soon obtain monopoly power with increasing amount of sales. Therefore, it is necessary to limit ourselves to just one phase of appropriability: technological appropriability. This is not the market condition but depending on the characteristics of R&D outcome and of the technical elements, for example, easiness to imitate or spill over, or not widely adopted by other firms due to R&D accumulation required. As mentioned above, it is difficult to define and capture both technological opportunity and appropriability in positive analyses, but they are definitely important in deciding the technological situation of the respective firm and industry. Without data well-defined in technological opportunity and appropriability, we have to establish a measurement framework which divides technology into its components. When this new approach is developed, a large part of the interindustry variance in R&D activities would become clearer.

[11] In this context, technical elements are considered to be corresponding to procedures such as chemical treatment and separation and mixing, usage of scientific techniques related to high polymer chemistry, mechanical engineering, optical mechanism, electronics, communication engineering, and so on. Discussion of technical elements first appears in Nakajo (1992).

[12] This is equal to market maturity: demand for a product does not increase even when its price goes down. This is also described as price elasticity.

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Note:
\normalsize
\caption{This is a 140mm*200mm figure.}
\label{fig1}
\end{figure}

%. Equation with a reference label
\begin{equation}
X=(I-A)^{-1}F
\label{IOtable}
\end{equation}

% References to Talbe, Diagaram, Equation and Bibliography.
Equation (\ref{IOtable}) is ...
Figure \ref{fig1} is ...
Table \ref{table1} is ...
See Author\cite{Label}, for example.

% Bibliography
\begin{thebibliography}{99}
\bibitem{Label}Author, Name(1993), ``Title of a paper,'' {\it Journal},
Vol.#, No.#, pp.###--###.
\bibitem{WL}Leontief, W.W.(1951), {\it The Structure of the American
Economy, 1919--1939: An Empirical Application of Equilibrium Analysis},
Oxford Univ. Press.
\end{thebibliography}
\end{document}
```