RESEARCH AND DEVELOPMENT DYNAMICS OF HIGH-TECH INDUSTRY

– TOWARD THE DEFINITION OF HIGH TECHNOLOGY –

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Final version received June 1986

Based on the observations made on the Japanese statistical data of R&D expenditures, we built a dynamic model of an R&D program. In this model, the concept of the cancellation rate function was introduced and three different function types were chosen for curve fitting.
By use of the non-linear least-square method, for each industry, one of the three types was selected as the best fitting type. On this basis, sectoral identification was made in terms of the dynamic characteristics of R&D activities. All the industrial sectors are classified as one of the three patterns: traditional pattern, science-based pattern and high-tech pattern.
Through this exercise, high-technology industry was identified as industry which is structurally different from traditional industry and from science-based industry in terms of the dynamic nature of its R&D investment. Thus, we were able to derive several tentative policy implications which are not yet well-known and have not yet been discussed.

Introduction

It is widely believed by students of innovation that innovation is a dynamic process [*1,2,3*]. However, there is a lesser degree of recognition of the dynamic nature of research and development (R&D) activities. As far as the classification scheme of R&D activities is concerned, there exists a well-established, conventional classification: basic research, applied research and development research. However, this classification is not a dynamic characterization of R&D activity, but a static one.

The U.S. Department of Defense (DOD) is not fully satisfied with the conventional classification. Therefore, the DOD uses a different classification for the purpose of effective management of its R&D activities. These are: fundamental research, exploratory development, advanced development, engineering development, and operational systems development [*4*]. For management, the consideration of cost becomes very important, especially the skewed distribution among various R&D activities. The DOD found that the total cost of R&D is distributed as follows: 5 percent of total cost is allocated for fundamental research, 10% for exploratory development, 20% for advanced development, 50% for engineering development, and 15% for operational systems development.

Although there might be various classification schemes established for management purposes at various institutions, what is important here seems to be the demarcation between the exploratory phase and the development phase.

Generally speaking, an analysis should be quantitative and proven statistically, in order to be scientific.

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However, as far as the study of R&D dynamics is concerned, there is, surprisingly, no such analysis, although there are some conceptual models which are neither quantitative nor statistical [*2,3,5*]. One of the major reasons for this lack is that there are no statistical data which reflect the dynamics of R&D activities.

1. *Data Base for Dynamics*

In order to make an analysis of R&D dynamics, we have to define the unit of R&D activity. John Enos, a pioneer in the study of the time interval between invention and innovation, identifies the date of an invention as "the earliest conception of the product in substantially its commercial form" and innovation as "the first commercial application or sale" [*6*]. He found, for example, that the radio was invented by de Forest in 1912 and the innovating firm was Westinghouse in 1920.

However, invention activity has become more organized recently. Therefore, it has become more difficult to identify the specific name of the inventor. Even in a study by Enos, for example, he described company chemists as the inventor of DDT (in 1939) and J.R. Geigy Co. as the innovating firm (in 1942).

Nowadays, invention activity is even more institutionalized, and hence it becomes almost impossible to identify the specific name of an individual or a firm as inventor or innovating firm in a scientifically meaningful way. All we can do is to identify the name of the country and of the industrial sector. The invention and innovation of the Video-Tape-Recorder illustrates this situation, i.e., all we can do is to identify the Japanese electronics industries as the innovating firms. Therefore, we had better think of inventive activity as being done by the industrial sector. Industrial R&D activity begins with an industrial sector's interest in a certain product and ends up with the establishment of a new key technology in this product field. This chain of R&D activities, which are focused on a certain product field, can be called an *R&D program*. The unusually rich Japanese R&D data collected in the Survey of Research and Development by the Statistics Bureau of the Prime Minister's Office provides us with the data base for this conceptualization of an R&D program. For all the Japanese companies with a capital of 100 million yen or more (3,803 companies in 1982), intramural expenditures for R&D is disaggregated into 31 different product fields.

A company like, say, Hitachi is asked in the survey instructions to break its R&D expenditures into such categories as chemical products, fabricated metal products, ordinary machines, household electric equipment, communication and electronic equipment, automobiles, precision instruments, etc. This is an alternative to reporting expenditures in one lump assigned to Hitachi's primary industry, i.e., electrical machinery manufacturing. In the case of expenses which are difficult to classify by the kind of product, they are divided proportionally on the basis of the number of researchers [7].

If an industrial sector's R&D is done within the existing product fields, which are directly related to its main business activity, i.e., the sector's principal product fields, the expenditures involve many activities, including mere improvement of existing products. Therefore, it is difficult to assume that the expense does reflect the R&D program conceptualized above. On the other hand, a sector's R&D expenditures outside its principal product fields can be assumed not to involve pure improvements of existing products, but to include only the R&D programs defined above. These investments can be easily canceled unless the prospects are favorable, because they are investments outside the main business activity at this stage. However, such cancellation is not easy in the case of investment within the principal product fields. On this basis, a sector's R&D expenditure in a certain product field outside its principal product fields can be assumed to correspond to a single R&D program, because the investment is focused on a certain product and does not include simple improvement of existing products [*8,9,10,11*].

2. *Statistical Characteristics of Data Base*

First, we have to distinguish two types of product fields for each sector: its principal product fields and those which are not. This distinction is made among manufacturing industries. In other words, every product field produced by manufacturing industries is to be classified into the principal product fields of one of the 21 manufacturing industrial sectors. The classification is shown in Table 1. Then, we can formulate the data availability of R&D expense as follows:

Let

E_{ijt} : *i*-th industry's R&D expense into *j*-th industry's principal product fields in *t*-th year, ($i, j = 1, ..., N$; $t = 1, ..., T$), where,

E_{iit} represents *i*-th industry's R&D expense into its principal product fields in *t*-th year, and,

D_t : research expenditure deflator of *t*-th year

Table 1. *Classification of Principal Product Fields*

No.	Name of industrial sector	Principal product fields
1.	Food mfg.	Food products
2.	Textile mill products mfg.	Textile products
3.	Pulp & paper products mfg.	Pulp & paper products
4.	Printing & publishing	Printing & publishing
5.	Industrial chemicals mfg.	Chem. ferrilizers and organic & inorganic chem. products Chemical fibers
6.	Oil & paints mfg.	Oil & paints
7.	Other chemical product mfg.	Other chemical products
8.	Drugs & medicines mfg.	Drugs & medicines
9.	Petroleum & coal products mfg.	Petroleum products
10.	Rubber product mfg.	Rubber products
11.	Ceramics	Ceramic products
12.	Iron & steel mfg.	Iron & steel
13.	Nonferrous metals & products mfg.	Non-ferrous metals
14.	Fabricated metal product mfg.	Fabricated metal products
15.	Ordinary machinery mfg.	Ordinary machinery
16.	Electrical machinery, equip. and supplies mfg.	Household electrical appliances Other electric equipment
17.	Communication & electronic equip. mfg.	Communication & electronic equipment and electric gauges
18.	Motor vehicles mfg.	Automobiles
19.	Other transp. equip. mfg.	Ships Aircraft Other transportation equipment
20.	Precision equip. mfg.	Precision instruments
21.	Other manufacturing	Other manufacturing products

Figure 1. *Frequency Distribution of R&D Expenses within Principal Product Field.*

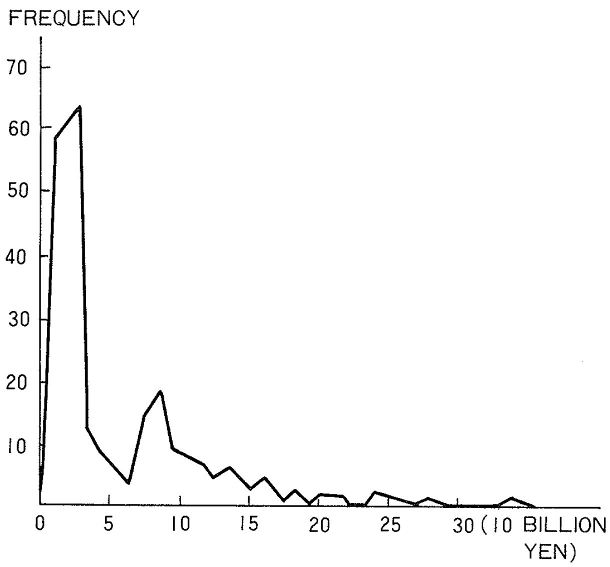
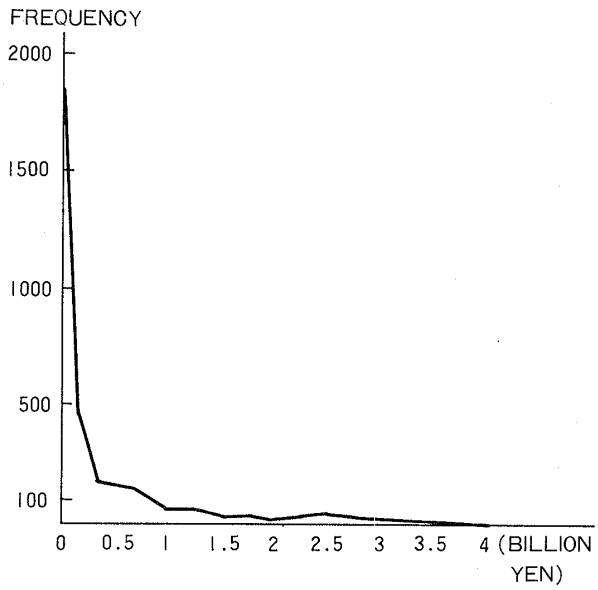


Figure 2. *Frequency Distribution of R&D Expenses outside Principal Product Field.*



(the reference year is 1975).

Then the real R&D expenditure for various product fields can be represented by

$R_{ijt} = E_{ijt}/D_t$.

Since the data is available every year from 1970 through 1982, we can pool a large amount of data, that is, 273 (21•13) data points for R&D within the principal product fields, and 5,460 (21•20•13) points for R&D outside the principal product fields.

The frequency distribution of all the R_{iit}'s (expense within principal product fields) are obtained as shown in Fig. 1, And the distribution of all the R_{ijt}'s $(i \neq j)$, that is, the expenses outside the principal product fields is shown in Fig. 2. As shown in the figures, the distribution for the principal product fields (Fig. 1) is assumed to be log–normal with two peaks, while the distribution for the expenses outside the principal product fields (Fig. 2) is assumed to be exponential.

The log–normal distribution with two peaks indicates that there are two groups of industries: one is highly R&D–intensive industry, i.e., industries whose average R&D expense is larger than 50 billion yen, and the other is less R&D–intensive industry, i.e., industries whose average annual R&D expense is smaller than 50 billion yen. Based on the central limit theorem, log–normality implies that the sample point includes various types of R&D programs with different natures, i.e., it includes various R&D programs, ranging from ones aiming at major breakthrough type innovations to ones aiming merely at improvement of existing products for product differentiation in existing markets. Therefore, we can conclude that the distribution of R&D expenses within the principal product fields does not reflect the dynamics of an R&D program.

On the other hand, the exponential distribution in Fig. 2 implies that almost all of the industry's R&D expenditures outside its principal product fields are for exploratory search and a few of them are for advanced development. We can assume, therefore, that the distribution in Fig. 2 faithfully reflects the dynamic process of an R&D program, where heavy investment is realized only after many exploratory searches are conducted over a long time and good potential has been demonstrated. Furthermore, it indicates the very nature of an R&D program, where almost all of the exploratory research projects turn out to be failures and very few of them can proceed to advanced development.

Based on the above reasoning and observations, we will make an analysis of the distribution in Fig. 2, i.e., that of the industrial sector's R&D expenses into product fields outside its principal product fields, to understand the dynamics of an R&D program.

3. *Mathematical Formulation of R&D Program Dynamics*

In order to construct a dynamic model, we need a dynamic interpretation of the exponential distribution obtained in Fig. 2. As time passes, an R&D program progresses from the exploratory phase through the advanced development phase. Thus, its annual investment increases with the passage of time as long as it shows potential. However, at any time when it is found to show little potential, it can be canceled, i.e., increase in its investment is no longer expected 1). On this basis, we can think of a survival type model of an R&D program's investment as follows:

Let

$R(C)$: the probability that an R&D program can survive until its annual investment reaches the amount of C,

then, the probability that an R&D program is canceled before it reaches the investment level of C, can be represented by

$1 - R(C)$.

Let

$f(C)$: the probability density function of C (the probability that an R&D program is canceled at the amount of C),

then, $f(C)$ can be represented by

$$f(C) = d/dC\,[1 - R(C)] = -R'(C). \qquad (1)$$

Let

$r(C)$: the cancellation rate of an R&D program whose investment level is C,

then, $r(C)$ can be formulated as the conditional probability that an R&D program is canceled, given that it can survive up to the investment level of C,

Therefore, $r(C)$ can be represented by

$$r(C) = f(C)/R(C) = -R'(C)/R(C). \qquad (2)$$

If the cancellation rate $r(C)$ is constant, i.e., independent of the investment level C, we can let $r(C) = r$; then the probability that the annual investment level of an R&D program is smaller than C, $R(C)$, can be derived

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1) This suggests that freezing the amount of investment for a research program is equal to cancellation of the research program. In the author's personal communication with Dr. Shogo Sakakura (Deputy Director General for Technological Affairs of MITI), it was ascertained that this assumption is empirically true. That is, in an R&D program which challenges unexplored fields of knowledge, it is very hard for anyone to conclude that the project has failed, and to decide to eliminate the entire expense all at once because the object is totally unknown, even if it becomes certain that the future of the program is not favorable. Therefore, research managers will decide only to freeze the research budget.

by equation (2) as follows:

$$R(C) = exp(-rC). \quad (3)$$

The probability density function that the annual investment of an R&D program is the amount of C, $f(C)$, can be derived as follows:

$$f(C) = r \cdot exp(-rC). \quad (4)$$

Therefore, we can derive an exponential distribution of an R&D program's investment, as observed in Fig. 2, by assuming that its cancellation rate is independent of its investment level.

4. *Typology of R&D Dynamics*

It is not always appropriate to assume that an R&D program's cancellation rate is independent of its investment level. In other words, we have to conceptualize the cancellation rate as the *cancellation rate function* of C.

First, exploratory research can be defined as that where the investment C is smaller, and advanced development can be defined as that whose C is larger. Second, the cancellation rate of exploratory research can be assumed to be higher, and that of advanced development to be lower, because the potential of an R&D program in the advanced development phase is already proven by the exploratory research which preceeds it.

Therefore, generally speaking, we can assume that the cancellation rate function $r(C)$ is a decreasing function of C, as shown in Figure 3. On this basis, the exponential curve is selected as a function type for the cancellation rate function as follows:

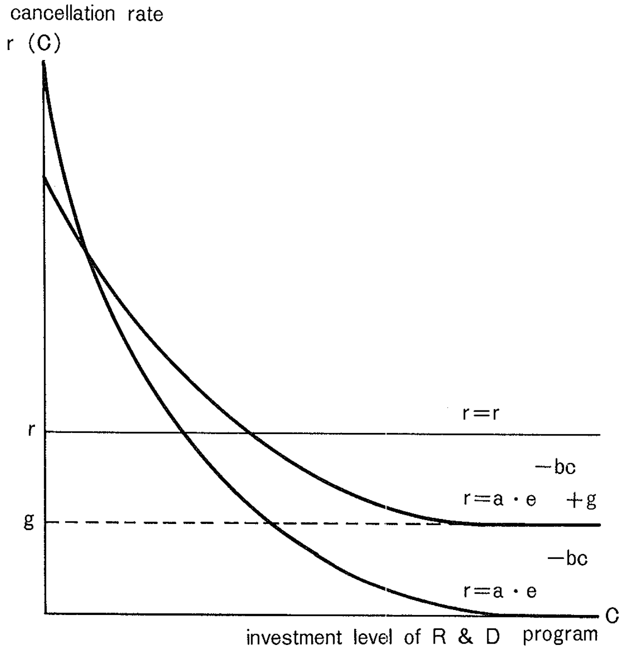
$$r(C) = a \cdot exp(-bC). \quad (5)$$

As can be seen in Fig. 3, function (5) assumes that the cancellation rate approaches zero in advanced development, i.e., there is no cancellation once a program enters an advanced development stage. This is a typical pattern observed in traditional industry. Therefore, we call it the *traditional pattern.*

On the other hand, in the function defined in (3), where $r(C) = r$, the cancellation rate is independent of the stage of development, i.e., high risks are involved in all the stages of development from fundamental research through engineering development. This pattern is observed in an industry where a scientific finding is directly related to its main business activities such as industrial chemical manufacturing. Therefore, we call this the *science-based pattern* [12].

Since the function type of (5) assumes that there is no more cancellation once exploratory research indicates good potential, there should be several industries

Figure 3. *Three Types of Cancellation Rate Function*



where this is not true. Therefore, one more function type is chosen for such industries as follows:

$$r(C) = a \cdot exp(-bC) + g, \quad (6)$$

where the cancellation rate approaches the non–zero value g, as shown in Fig. 3, so the possibility of being cancelled exists even in the case where a program enters a very advanced development stage.

In this function type, there remains a certain possibility of being cancelled even after an R&D program enters into advanced development, i.e., development programs have to be cancelled if someone else finds another technology which can fulfil the performance level of the products but which is based on a different scientific principle. One such example can be found in the series of innovations in which the vacuum–tube was followed first by the transistor and later by the integrated-circuit [13]. This is observed in the so-called high-technology industries, where several major innovations can occur one after another or simultaneously, as waves coming to shore. Therefore, we call this the *high-tech pattern.*

5. *Statistical Tests of Dynamic Model*

Method of Estimation For the cancellation rate, we choose the following three types of function:

- type (*I*) $r(C) = r$, (science-based pattern),
- type (*II*) $r(C) = a \cdot exp(-bC)$, (traditional pattern),
- type (*III*) $r(C) = a \cdot exp(-bC) + g$, (high-tech pat-

tern).

However, the data for each industrial sector are available only in the form of the probability density function of C. Therefore, we have to derive the probability density function for each type of cancellation rate function.

On the basis of the equation (2), we can derive the following two equations:

$$R(C) = exp[-\int_{t=0}^{t=C} r(t)dt], \qquad (7)$$

and,

$$f(C) = r(C) \cdot R(C). \qquad (8)$$

Using these two equations, which are applicable for all the three types of cancellation rate, we can derive the probability density function $f(C)$ as follows:

For type (I), $\int_0^C r(t)dt = r \cdot C$, therefore,

$$f(C) = r \cdot exp(-rC);$$

For type (II), $\int_0^C r(t)dt = a \cdot [-(1/b) \cdot exp(-bC) + (1/b)]$, hence,

$$f(C) = a \cdot exp[(a/b) \cdot (exp(-bC) - (b/a) \cdot C - 1)];$$

For type (III), $\int_0^C r(t)dt = -(a/b) \cdot [exp(-bC) - 1] + gC$, hence,

$$f(C) = [a \cdot exp(-bC) + g] \cdot exp[(a/b) \cdot (exp(-bC) - 1) - gC].$$

For each of 21 industrial sectors, the R&D expenses into 20 product fields outside its principal product fields are available from 1970 through 1982. Therefore, for each industrial sector, we can use 260 (=20·13) data points for curve fitting of $f(C)$. For the curve fitting, a non-linear least-square method, the Marquard Method, is used.

Results of Estimation The result of curve fitting of the science-based pattern (type I) is shown in Table 2, with the coefficient of determination and T-value in parentheses under the estimated value of the parameters. In the table, all the T-values are much larger than 2.02; hence, we can reject the hypothesis that $r = 0$ at a significance level of 95%. However, not all the coefficients of determination are high enough: especially, they are quite low in such sectors as ordinary machinery and electrical machinery.

For fitting of the traditional pattern (type II), the result is shown in Table 3, with T-values in parentheses under the estimated parameter values. In the sector termed "other manufacturing," we can not complete the estimation process because the convergence conditions are not met. However, we can reject the hypothesis that $a = b = 0$ in all the sectors except industrial chemicals. Furthermore, the coefficients are improved in all the sectors compared with those in Table 2. However, the coefficient of determination is not high enough in ordinary machinery.

For fitting of the high-tech pattern (type III), the result is shown in Table 4, with T-values in parentheses under the estimated parameter values. The coefficient of determination is further improved in all the sectors, and none of them are lower than 0.8. However, except for those sectors such as drugs & medicines, ordinary machinery, electrical machinery, communications & electronics and precision machinery, we can not rule out $g = 0$. And in only these five sectors, we can reject that $a = b = g = 0$.

Table 2. *Statistical Test of Science Based Pattern*

Name of industrial sector	r	Coefficient of determination
Food mfg.	0.4467 (26.64)	0.8532
Textile mill products mfg.	0.3301 (25.71)	0.8991
Pulp & paper products mfg.	0.5628 (15.14)	0.9264
Printing & publishing	0.5427 (13.00)	0.9057
Industrial chemicals mfg.	0.0830 (37.77)	0.8858
Oil & paints mfg.	0.4616 (25.77)	0.8684
Drugs & medicines mfg.	0.5269 (21.05)	0.8782
Other chemical product mfg.	0.3804 (31.61)	0.9293
Petroleum & coal products mfg.	0.4669 (19.09)	0.8786
Rubber products mfg.	0.4578 (15.02)	0.8966
Ceramics	0.2985 (27.99)	0.8953
Iron & steel mfg.	0.2871 (27.04)	0.8865
Nonferrous metals & products mfg.	0.2706 (23.08)	0.9193
Fabricated metal product mfg.	0.2886 (24.06)	0.9213
Ordinary machinery mfg.	0.1535 (18.20)	0.7169
Electrical machinery mfg.	0.2301 (42.30)	0.6558
Communication & electronics mfg.	0.4232 (86.97)	0.8776
Motor vehicles mfg.	0.2753 (49.00)	0.9482
Other transp. equip. mfg.	0.3989 (80.57)	0.9452
Precision equip. mfg.	0.3969 (21.31)	0.8738
Other manufacturing	0.1688 (18.90)	0.8631

Table 3. Statistical Test of Traditional Pattern

Name of industrial sector	a	b	Coefficient of determination
Food mfg.	0.4439 (32.15)	0.3955 (8.48)	0.9142
Textile mill products mfg.	0.3306 (26.36)	0.1889 (5.67)	0.9197
Pulp & paper products mfg.	0.5681 (65.08)	0.5737 (16.14)	0.9965
Printing & publishing	0.5309 (12.92)	0.3236 (2.45)	0.9204
Industrial chemicals mfg.	0.0844 (33.68)	0.0102 (1.85)	0.8864
Oil & paints mfg.	0.4513 (26.68)	0.3220 (6.13)	0.8967
Drugs & medicines mfg.	0.5376 (66.34)	0.6793 (18.01)	0.9889
Other chemical product mfg.	0.3840 (43.69)	0.2627 (10.37)	0.9683
Petroleum & coal products mfg.	0.4768 (37.51)	0.5200 (10.42)	0.9722
Rubber products mfg.	0.4507 (15.19)	0.2681 (3.03)	0.9153
Ceramics	0.2995 (28.06)	0.1478 (5.39)	0.9111
Iron & steel mfg.	0.2968 (35.5)	0.2261 (9.91)	0.9451
Nonferrous metals & products mfg.	0.2772 (24.36)	0.1372 (4.80)	0.9388
Fabricated metal product mfg.	0.2991 (30.06)	0.1879 (7.25)	0.9571
Ordinary machinery mfg.	0.1753 (19.36)	0.1399 (6.36)	0.7894
Electrical machinery mfg.	0.3029 (100.40)	0.6336 (37.09)	0.9344
Communication & electronics mfg.	0.4460 (273.30)	0.5211 (79.87)	0.9885
Motor vehicles mfg.	0.2777 (53.76)	0.1454 (11.06)	0.9643
Other transp. equip. mfg.	0.3998 (112.10)	0.2680 (25.82)	0.9755
Precision equip. mfg.	0.4153 (52.28)	0.4657 (15.58)	0.9813
Other manufacturing	—	—	—

6. *Identification of Sectoral Pattern*

Decision Rule for Identification The identification problem here means the selection of the best cancellation rate function among the three candidates, i.e., type (*I*), (*II*) and (*III*). The criteria for the choice are the degree of fitness and the level of significance. This can be implemented by the choice of the type whose coefficient of determination is the highest as long as the *T*-values of all the parameters are larger than the values specified by the significance level. Therefore, the procedure for selection can be described by the flow chart shown in Fig. 4.

Results of Identification Based on the flow chart described in Fig. 4, the best function type is chosen. Thus, the results of identification are obtained as follows:

The industries identified as the science-based pattern, type (*I*), are:

industrial chemicals;
other manufacturing.

The industries identified as the high-tech pattern, type (*III*), are:

drugs & medicines;
ordinary machinery;
electrical machinery;

Table4. *Statistical Test of High-Tech Pattern*

Name of industrial sector	a	b	g	Coefficient of determination
Food mfg.	0.4411 (29.94)	0.4016 (8.15)	0.0029 (0.52)	0.9145
Textile mill products mfg.	0.3292 (20.79)	0.1906 (5.30)	0.0015 (0.14)	0.9198
Pulp & paper products mfg.	0.5602 (50.68)	0.5963 (14.28)	0.0083 (1.13)	0.9968
Printing & publishing	0.5535 (7.40)	0.2971 (1.92)	−0.0229 (0.36)	0.9212
Industrial chemicals mfg.	0.1112 (0.32)	0.0062 (0.11)	−0.0274 (−0.08)	0.8865
Oil & paints mfg.	0.4505 (24.42)	0.3233 (5.94)	0.0009 (0.11)	0.8967
Drugs & medicines mfg.	0.5303 (63.24)	0.7069 (17.88)	0.0077 (2.23)	0.9900
Other chemical product mfg.	0.3819 (37.51)	0.2664 (9.82)	0.0022 (0.40)	0.9683
Petroleum & coal products mfg.	0.4679 (31.06)	0.5484 (9.77)	0.0095 (1.43)	0.9735
Rubber products mfg.	0.4575 (9.91)	0.2597 (2.55)	−0.0069 (−0.19)	0.9154
Ceramics	0.2991 (21.43)	0.1482 (5.08)	0.0004 (0.04)	0.9111
Iron & steel mfg.	0.2908 (29.40)	0.2390 (9.25)	0.0065 (1.10)	0.9461
Nonferrous metals & products mfg.	0.2776 (15.00)	0.1367 (4.15)	−0.0005 (−0.03)	0.9388
Fabricated metal product mfg.	0.2947 (21.73)	0.1950 (6.47)	0.0047 (0.48)	0.9573
Ordinary machinery mfg.	0.1463 (10.48)	0.2474 (4.28)	0.0356 (2.97)	0.8013
Electrical machinery mfg.	0.2764 (100.30)	0.8036 (35.98)	0.0294 (21.19)	0.9569
Communication & electronics mfg.	0.4454 (272.10)	0.5236 (79.87)	0.0008 (3.32)	0.9886
Motor vehicles mfg.	0.2762 (43.02)	0.1471 (10.71)	0.0016 (0.39)	0.9644
Other transp. equip. mfg.	0.3996 (108.00)	0.2683 (25.57)	0.0002 (0.22)	0.9755
Precision equip. mfg.	0.4045 (47.31)	0.5027 (16.23)	0.0118 (2.75)	0.9841
Other manufacturing	–	–	–	–

communications & electronics;

precision machinery.

The industries identified as the traditional pattern, type (*II*), are:

all the other 14 industries.

Although "industrial chemical manufacturing" is a typical science-based industry, "other manufacturing" is not obviously so. However, it is classified as this pattern, mainly because it includes so many different industries and the estimation process in the curve fitting of the other two function types is not terminated.

7. *Definition Problems of High-Technology*

Conventionally, there are two ways of defining high technology:

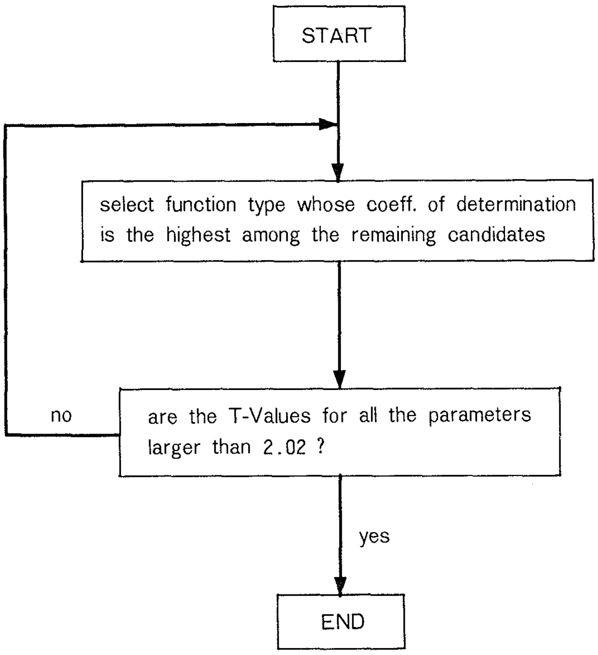
(1) based on the industry, from the viewpoint of its technology- and R&D-intensiveness; or

(2) based on the individual product, from the viewpoints of its attributes and its technological sophistication.

Although the latter approach is desirable, data availability limits the feasibility of doing so. Therefore, the former approach is widely adopted by various governmental branches in various countries.

One of the well-known definitions, for example, is

Figure 4. *Flow Chart for Sectoral Identification*



the one used by the Bureau of Economic Analysis, U.S. Department of Commerce. Based on the three or four digits of the SIC (Standard Industrial Classification Code), the BEA defines high-tech industry as an industrial sector which satisfies one of the following two conditions:

(1) the percentage of the sector's R&D expense in its value-added output is larger than 10 percent; or

(2) the percentage of the sector's number of S/E's (scientists and engineers) in its total employment is larger than 10 percent.

Based on these criteria, the BEA selected the following products: *Drugs* (283), *Office, computing & accounting machines* (357), *Electrical machinery* (36), *Aircraft & parts* (372), and *Guided missiles & space vehicles* (376), where the code number is shown in the parenthesis [*14*]. However, in the competitive assessment study, the BEA selected the following industries: *Drugs & medicines, Business machines & equipment, Computers, Electrical & electronic machines & equipment, Telecommunication equipment, Electronic components, Consumer electronics, Jet engines, Aircraft, and Scientific instruments* [*15*].

In Japan, the MITI uses the SITC (Standard International Trade Classification) and selected the following products: *Machine-tools* (736), *Automatic data processing machines & units there of* (7521, 7522, 7523, 7528), *Transistors & similar semiconductor devices* (7764); *Aircraft & associated equipment* (792), and *Video-Tape Recorders* [*16*].

Therefore, we can conclude that those industrial sectors classified as the high-tech pattern in our study do surprisingly coincide with those selected by various administrative agencies as high-tech industries.

However, in the conventional ways of defining high-technology, there is no essential difference between the definition for R&D-intensive industry and that for high-tech industry [*17*]. The definition seems to tell us that high-tech industry is nothing but highly R&D-intensive industry. However, the word "high-tech" should mean something more than just R&D-intensive industry.

Therefore, there should be a structural difference in R&D activities between high-tech and R&D-intensive industries. Hence, for the definition of high-technology, we should pay more attention to the structure of R&D activities. This is essentially what we did in this paper. Therefore, we can claim that our approach is more appropriate than the conventional ones because our distinction is based on a structural difference.

On the basis of our analysis, we can define traditional industry as that in which an R&D program is no longer in danger of being canceled after it reaches an advanced development stage, i.e., this risk disappears once a key technology is established. On the contrary, science-based industry is defined as that in which the danger of an R&D program being canceled remains at the same level in all stages of its development, i.e., the same level of risk is involved regardless of the development stage. In between, high-tech industry is defined as that in which the danger of being canceled decreases but remains at a certain level even after an R&D program reaches an advanced development stage, i.e., a certain risk can not be eliminated even when a key technology is established.

8 *Policy Implications*

If we define high-tech industry in a conventional way, we can not derive any policy implication which is new and different, i.e., the policy towards high-tech industry would be an extension of what we have for R&D-intensive industry. A recommendation to policy planners might be that more money should be spent on R&D and more S/E's should be recruited to promote high-tech industry; and the government should support basic research because a private company can not afford it any more; and so forth.

On the other hand, the policy implication which will be derived from our study will be quite different from a mere extension of the existing policies for R&D-intensive industry. Let us describe some of the tentative lessons drawn directly from our analysis, as far as the relationship between R&D management and corporate management is concerned.

In traditional industry, a key technology is more or less treated as a given; therefore, the problem is how and when capital investment commercializing the key technology is done so that its rate of return is maximized. Hence, we can separate R&D management from corporate management.

In science-based industry, on the other hand, R&D management is closely linked to its survival in business. However, this is a sort of management of the unmanageable, because we have to manage basic science [*18*]. Therefore, in this industry also, we can separate R&D management from corporate management. Here, a concern of management is how to hedge against high risks. All we can do is to build a strong financial base for the company, in order to support as many basic research programs as possible [*19*].

In high-tech industry, however, the situation is quite different from that in these two types of industry, i.e., traditional and science-based industry. R&D activity, especially basic research, needs to be organized and managed, and it can be done to some extent, i.e., organized and targeted basic research is more important than random support of basic research. Therefore, R&D management cannot be separated from corporate management, and these two types of management should be consolidated [*20*]. This can be done, for example, by having as president a manager who has technical insight and the prior experience of being engaged in R&D activity. A large number of application-minded basic researchers is also absolutely necessary.

However, at this stage it is premature to draw any specific policy implications from our study. All we can say here is that we should recognize the structural difference of high-tech industry, and a careful study should be made on the basis of this recognition.

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