Articles

Technological Diversification of Japanese Industry

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A Japanese database on research and development that disaggregates an industry's intramural expenditure into 31 different product fields is used to measure technological diversification. Sectoral patterns are identified in terms of upstream, downstream, and horizontal diversification—that is, respectively, diversification of an industry's research and development activities into product fields that are industrial inputs of that industry, into those that are outputs, and diversification that is not directed through the path of input-output relations. The pattern of the electronics industry is identified as downstream diversification whereas that of the chemical industry is identified as horizontal. The declining industry is generally making upstream diversification. Japanese corporate and governmental policies, such as trade policy, industrial policy, and the research association scheme, have accelerated technological diversification.

IT IS WIDELY RECOGNIZED THAT A COUNTRY'S ECONOMIC restructuring requires technological changes. More recently, industrial research and development has been identified as one important source of technological change. However, there is surprisingly little solid quantitative evidence linking industrial R&D with economic restructuring.

A drastic change in a country's economic structure occurs when a new industry is created, an existing industry disappears, or both. Therefore, in this connection, a more relevant dichotomy is whether or not a sector's industrial R&D is done within or outside its principal product fields. The industrial R&D conducted by each sector within its principal product fields is supposed to be directed toward keeping existing industries viable. The industrial R&D activity outside the principal product fields is directed toward creating new industries.

Each sector's R&D activity outside its principal product fields can be considered "technological diversification" of that industry. Therefore, a study of technological diversification of existing industries leads to the study of creation of new industries. This is true in Japan, where internal corporate venturing (*1, 2*) is a dominant mode for creating new industries based on technological diversification.

In this article, first an approach to measuring an industry's technological diversification behavior is described. Then, the sectoral patterns of Japanese industry are identified, as far as the diversification behavior is concerned. Finally, Japanese corporate and governmental policies relevant to diversification are discussed in terms of their mechanisms and effectiveness.

Database

Japanese database for diversification studies. Two attempts have been made to identify the sectoral pattern of technological diversification: the work on significant British innovations by Pavitt (*3*) and the work on U.S. patents by Scherer (*4*). The unusually rich Japanese R&D data source collected in the *Survey of Research and Development* by the Statistical Bureau of the prime minister's office (*5*) makes it possible for us to take a third approach. For all the Japanese companies with a capital of 100 million yen or more (3803 companies in 1982), intramural expenditure on R&D is disaggregated into 31 different product fields.

A company like Hitachi, for instance, was asked for this survey 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, and so forth. This is an alternative to reporting expenditures in one lump assigned to Hitachi's primary industry, electrical machinery manufacturing. In the case of an expense that is difficult to classify by the kind of product, it is divided proportionally on the basis of the number of researchers (*5*).

This survey is available for every year since 1970 so that time series analysis is possible and investigations at any particular point in time can be checked. Moreover, because this survey is authorized by a special law (Shitei-Toukei), it is thought that the companies complete the survey with great care.

Profile of diversification. From this database, a profile showing how each industry diversified its R&D activities during the 1970's can be drawn. The textile industry was chosen as an example because it was one of the most diversified industries during the period.

This kind of profile (Fig. 1) shows product fields as a function of the industry's R&D expenses. Product fields are arranged in decreasing order of the expense in 1970 so that "textile products," the largest expense item, is at top; "chemical fibers," the second largest expense item, is next; and so on. The 1970 profile is a monotone curve, whereas those for 1975 and 1980 are no longer simple monotone curves, showing visually how the rank order of the expenses in product fields has changed since 1970.

The industry's expense in the product field of "building construction," for example, was nothing in 1970, was substantial in 1975, and became one of the largest expenses by 1980. There was no investment in "drugs and medicines" in 1970, but it was the fourth largest expense item in 1980.

Since this profile was drawn on the basis of R&D expenses, it does not necessarily describe the product diversification of a specific

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Table 1. Classification of principal product fields.

Industrial sector	Principal product fields
Agriculture	Agricultural, forest, and fishing products
Mining	Mining products
Construction	Building construction and civil engineering
Food	Food products
Textile mill products	Textile products
Pulp and paper products	Pulp and paper products
Printing and publishing	Printing and publishing
Chemical products	Chemical fertilizers and inorganic and organic chemical products; chemical fibers; oil and paints; other chemical products
Drugs and medicines	Drugs and medicines
Petroleum and coal products	Petroleum products
Rubber products	Rubber products
Ceramics	Ceramic products
Iron and steel	Iron and steel
Nonferrous metals and products	Nonferrous metals
Fabricated metal product	Fabricated metal products
Ordinary machinery	Ordinary machinery
Electrical machinery	Household electrical appliances; communication and electronic equipment; other electric equipment
Motor vehicles	Automobiles
Other transport equipment	Ships; aircraft; railroad equipment; other transportation equipment
Precision equipment	Precision instruments
Other manufacturing	Other manufacturing products

company. However, company that was a textile industry may now be applying its fiber technology to building materials or to filters for medical equipment such as those used in kidney dialysis.

Measurement of Diversification

Degree of diversification. Several quantitative analyses on diversification can be made from this database. First is the degree of diversification. If an industry's R&D distribution over the different product fields (Table 1) is considered as a probability distribution, we can construct an indicator for degree of diversification, using the concept of entropy.

Given E_{ij} (ith industry's R&D expense into jth product field) and allowing p_{ij} to be the share of the jth product field in the total R&D expense of ith industry ($p_{ij} = E_{ij}/\Sigma_j E_{ij}$), then H_i, the entropy of the ith industry, can be calculated by $H_i = -\Sigma_j p_{ij} \ln p_{ij}$.

If an industry's diversification is advanced and its R&D expenses cover many product fields, with less concentration on specific fields, then the industry's entropy value rises. On the other hand, if an industry's diversification is not as advanced and its R&D expenses cover only a few product fields with a high concentration on specific fields, then the industry's entropy value drops. A time series of entropy values of major industries (Fig. 2) shows that the textile industry is the most diversified industry, motor vehicle manufacturing the least diversified, and iron and steel is in between.

During the 1970's, the textile industry and petroleum and coal products manufacturing saw rapid diversification, while the other industries did not experience much change in diversification.

There may be several ways to interpret these results. One clear result, however, is that an industry's degree of diversification is related to its growth rate of production in its principal product field (textile products in the textile industry and automobiles in motor vehicle manufacturing). In other words, the higher the growth rate of production of an industry's principal products, the lower is its degree of diversification and less drastic is its change (motor vehicles, for example). On the other hand, the more saturated an industry's production of its principal products is, the higher is its degree of diversification and its change (textiles, for example). This suggests that diversification may be used as a survival strategy for a declining industry. This is especially true in Japanese industry, where the life employment system is built into management practice; managers are motivated to diversify to keep the employment constant.

R&D investment for diversification. Since an industrial sector's technological diversification is defined as the sector's R&D activity outside its principal product fields, the principal fields must be distinguished from those that are not.

In the Statistical Bureau's survey, however, a given company's R&D expenditures, although disaggregated by product field, are not disaggregated industry by industry but are assigned entirely to the firm's primary industry. Many Japanese companies operate in several industries. Therefore, in order to overcome this problem, the 25 industrial sectors in the survey are combined into 21 sectors in this analysis (Table 1). For example, "electrical machinery, equipment, and supplies manufacturing" and "communication and electronic equipment manufacturing" are combined into one industrial sector, "electrical machinery manufacturing." And "industrial chemicals manufacturing," "oils and paints manufacturing," and "other chemical product manufacturing" are combined under "chemical products manufacturing." On the other hand, "transportation equipment manufacturing" is disaggregated into "motor vehicles manufacturing" and "other transportation equipment manufacturing," because the major industry of "other transportation equipment" is the shipbuilding industry, as far as the Japanese statistics are concerned. And "transport, communication, and public utilities" is dismissed in our database because it is the service industry and covers many different companies from railroad service through electric utility.

After this reorganization of industrial sectors, the product fields are classified into the principal product fields of one of the 21 industrial sectors (Table 1). This classification is not difficult to do because most of the product fields are identical to the names of industrial sectors.

Each sector's R&D expenditure outside its principal product fields (denoted by B) and its relative size in terms of its ratio to total expenditure (denoted by A) is calculated as shown in Table 2. The amount of R&D expenditure spent by all industries outside their principal product fields was 447 billion yen in 1980, which corresponds to 19% of their total R&D expenditures.

Industries for which expenses outside principal product fields exceed those for principal fields ($B/A > 0.5$) are mining, textiles, fabricated metal products, and other transportation equipment. The industries in which both types of expenditures are comparable are petroleum and coal, ceramics, and nonferrous metals. The industries in which the expenses outside the principal product fields are minimal compared to those for principal product fields ($B/A < 0.1$) are agriculture, drugs and medicines, and motor vehicles.

Sectoral Patterns of Diversification

Typology of diversification. Industries can diversify their R&D activities in a number of directions. The purpose here is to identify these directions in relation to industrial structure. Therefore, it is important to see how the industries are interrelated. One interrelation that can be identified empirically is that of input to output.

If an industry diversifies its R&D activities into product fields that are either inputs or outputs of that industry, the direction of diversification is called "vertical." If an industry does not diversify through the path of input-output relations, the direction is called "horizontal."

There are two types of vertical diversification: "upstream" and "downstream." If the industry's R&D activities are diversified into product fields that are inputs, the direction of diversification is upstream. If they are diversified into the outputs, the direction is downstream.

Measurement of direction. The measurement problem can be formulated as follows: to what extent does the direction of R&D investment, which is given by the distribution of R&D expense into product fields, follow an upstream or downstream direction (as given by the input-output transaction table)?

Given E_{ij} (ith industry's expense into jth industry's principal product fields, for $i, j = 1, 2, \ldots, n$) and letting $E_{ii} = 0$ because we are interested in diversification—that is, expenses outside principal product fields—then, the ith industry's direction of R&D investment can be described by the vector $\vec{e}_i = [e_{i1}, e_{i2}, \ldots, e_{in}]$, where $e_{ij} = E_{ij}/\Sigma_j E_{ij}$.

Given T_{ij} (the amount of transaction from ith industry to jth industry) and letting $T_{ii} = 0$, then the ith industry's upstream direction is represented by the vector $\vec{u}_i = [u_{1i}, u_{2i}, \ldots, u_{ni}]$, where $u_{ij} = T_{ij}/\Sigma_i T_{ij}$. Therefore, U_i, the degree of upstream diversification of the ith industry, can be measured by $U_i = \vec{u}_i \cdot \vec{e}_i$, the inner product of the two vectors. In other words, the higher the U_i value, the closer is the direction of ith industry's R&D investment to the ith industry's upstream direction.

Similarly, the ith industry's downstream direction is represented by the vector $\vec{d}_i = [d_{i1}, d_{i2}, \ldots, d_{in}]$, where $d_{ij} = T_{ij}/\Sigma_j T_{ij}$; then D_i, the degree of downstream diversification of ith industry, can be measured by $D_i = \vec{d}_i \cdot \vec{e}_i$. The calculated values of the degree of upstream diversification and of downstream diversification are shown in Table 2.

Among the fairly diversified industries (the ratio of B to A is higher than the average 0.19), the industries with the most strongly developed path of upstream technological diversification are textiles, pulp and paper products, and other transportation equipment. The industries with the strongest path of downstream diversification are petroleum and coal products, iron and steel, nonferrous metals, and precision equipment. However, there are some industries without any strong path of vertical diversification—neither upstream nor

Table 2. Measurement of diversification, for 1980.

Industrial sector	A, total R&D expense (10^9 yen)	B, expense outside principal products (10^9 yen)	B/A	Upstream (U_i)	Downstream (D_i)
Agriculture	2.2	0.10	0.04	0.396	0.811
Mining	8.9	6.25	0.70	0.032	0.033
Construction	53.0	9.55	0.18	0.042	0.059
Food	59.6	19.34	0.32	0.055	0.099
Textiles	17.9	9.64	0.54	0.328	0.026
Pulp and paper	13.1	2.42	0.19	0.203	0.137
Printing and publishing	4.8	1.24	0.26	0.047	0.057
Chemical products	285.3	45.58	0.16	0.026	0.058
Drugs and medicines	162.3	10.87	0.07	0.235	0.205
Petroleum and coal	24.7	11.28	0.46	0.035	0.154
Rubber products	42.9	6.33	0.15	0.136	0.424
Ceramics	62.1	26.18	0.42	0.058	0.073
Iron and steel	188.2	26.23	0.22	0.032	0.179
Nonferrous metals	37.5	15.48	0.41	0.031	0.146
Fabricated metals	38.4	20.36	0.53	0.024	0.079
Ordinary machinery	154.3	37.60	0.24	0.119	0.111
Electrical machinery	666.3	74.55	0.11	0.063	0.243
Motor vehicles	370.0	27.47	0.07	0.083	0.118
Transport equipment	71.1	47.32	0.67	0.274	0.010
Precision equipment	66.4	19.34	0.29	0.074	0.247
Other manufacturing	60.4	30.40	0.50	0.402	0.075
Total	2319.4	447.16	0.19		

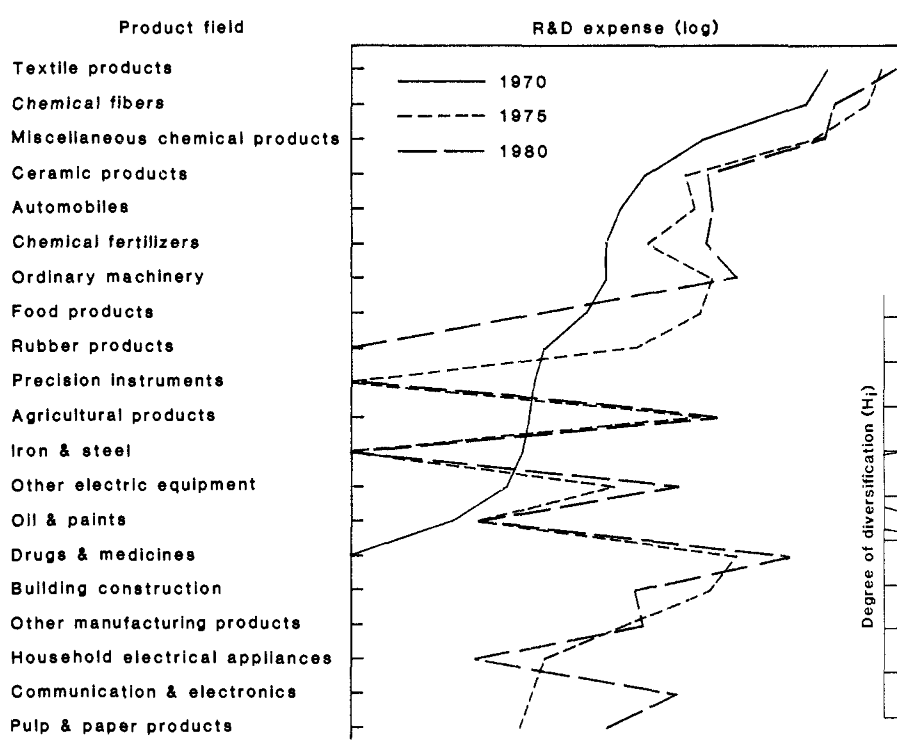


Fig. 1. Profile chart for diversification in the textile industry.

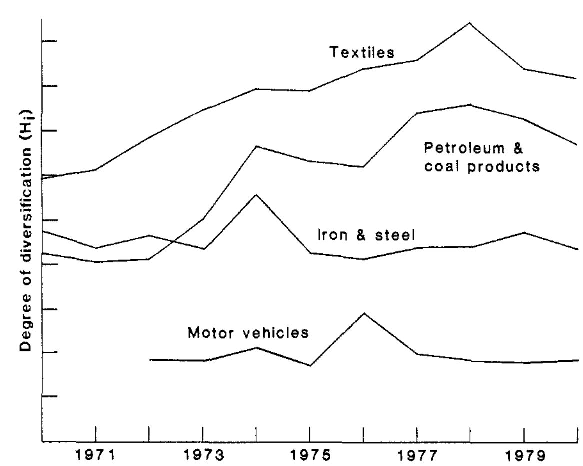


Fig. 2. Measurement of diversification of major industries.

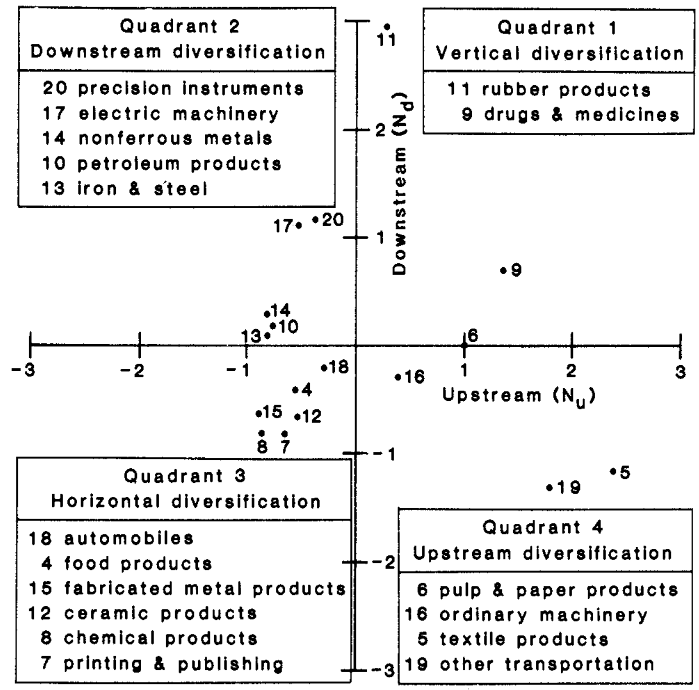


Fig. 3. Identification of sectoral patterns.

downstream. Because they are diversified, we assume that they follow the path of horizontal diversification. These are mining, printing and publishing, ceramics, and fabricated metal products.

It should be noted that the degree of upstream and downstream diversification measured through this analysis is only concerned with technological diversification because our database is the allocation of R&D expenses into product fields. Technological diversification does not always lead to product diversification. For instance, an upstream industry such as iron and steel manufacturing can become more technologically diversified toward the further upstream direction by being engaged as an engineering company. In order to engage in engineering business, the industry has to diversify its R&D activities into those product fields that are among its industrial inputs. Indeed, the active membership of the Engineering Advancement Association of Japan, beyond engineering companies and construction companies, is composed of the major iron and steel companies and shipbuilding companies.

Identification of sectoral patterns. There are some industries with a strong path of both upstream and downstream diversification, such as drugs and medicines and rubber products. In other words, although two U_i's or two D_i's can be compared to each other, U_i cannot be directly compared to D_i. In order to make them comparable, both U_i and D_i have to be normalized.

The normalized value of U and D can be calculated by $N_u = (U - M_u)/S_u$, and $N_d = (D - M_d)/S_d$, where M_u and M_d are the average of U and D, respectively, and where S_u and S_d are the standard deviations of U and D, respectively. By plotting of (N_u, N_d) in the plane, we can classify sectoral patterns of technological diversification into four categories (Fig. 3).

In Fig. 3, quadrant 2 includes industry that has strong downstream diversification (D_i is above average) but weak upstream diversification (U_i is below average). Therefore, the sectoral pattern in this quadrant is identified as downstream diversification. By the same token, quadrant 4 includes industry that has strong upstream but weak downstream diversification. Therefore, the pattern in this quadrant is identified as upstream diversification.

Quadrant 3 includes industry that has both weak upstream and downstream diversification and is thus supposed to have strong horizontal diversification. Therefore, industry in this quadrant is identified as having horizontal diversification. Finally, quadrant 1 includes industry that has both strong upstream and downstream diversification. The sectoral pattern can be identified as vertical diversification. The normalization and classification were made for manufacturing industries (Fig. 3).

The industries that can clearly be classified as having upstream diversification are textiles and other transportation equipment. They are more or less mature industries in the sense that they are being overtaken by those in newly industrialized countries. Therefore, they are diversifying toward the upstream direction in order to keep afloat in international competition.

Those clearly classified as showing downstream diversification are electrical machinery and precision equipment. These were the first and second in terms of growth rate in the period after the oil crisis. Moreover, the "mechatronics revolution," the combination of mechanical technology and electronics technology, which occurred around 1975 in Japan, widened applications for these technologies and hence induced them to diversify into downstream sectors (*6, 7*). We might generalize that a drastic growth of industry can only be fostered by downstream diversification.

Those that can be clearly classified as showing horizontal diversification include chemical products and fabricated metal products. Since they are typical material industries, their diversification is rather free from industrial structural relations. Drugs and medicines, in which the introduction of biotechnology is supposed to be promising, shows vertical diversification—both upstream and downstream. Industries whose direction of diversification cannot be clearly identified are motor vehicles and ordinary machinery.

Policies for Diversification

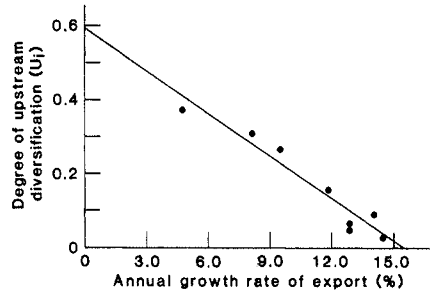
Japanese management and diversification. It is often said that chemical products manufacturing and electrical machinery manufacturing are similar because both are examples of so-called "science-based" industry (*8*). Therefore, it is argued that a country whose ratio of basic research in its total R&D budget is high and that of its public science in total R&D is also high has an advantage in these two industries. The Japanese ratios are the lowest among the advanced countries.

However, the investments are different; Japan has a strong electronics industry but not a strong chemical industry. The industries are also different in technological diversification—that is, electrical machinery manufacturing is classified as downstream diversification, and chemical products manufacturing is classified as horizontal diversification.

Although both industries are "science-based," basic research in the electronics industry has a clear-cut direction, whereas basic research in the chemical industry is undirected, requiring broad-based support in basic research. Therefore, in the electronics industry, management can direct an innovation cycle from basic research to commercialization, using a team approach. Management of basic research is difficult in the chemical industry because managers have to rely on the contributions from a few very talented individuals.

The pharmaceutical industry, which used to be quite similar to the chemical industry, has changed because of the emergence of biotechnology. The direction of diversification in the former has become more clear—that is, a vertical diversification scheme; the chemical industry still follows horizontal diversification. This may be one reason why it is suggested that Japan may soon become the leading competitor of the United States in pharmaceuticals (*9*).

Fig. 4. Relation between export growth and upstream diversification.



Trade policy. In the 1960's, Japanese governmental policies had been focused on export promotion; in the 1970's, removing trade barriers was central (*10, 11*). Therefore, our database available every year since 1970 makes it possible to analyze industry response to the trade liberalization policies as far as diversification is concerned.

To test the assumption that an industry's loss in international competitiveness leads to upstream diversification (*12*), industries whose growth rate of export is below average (the annual growth rate of Japanese industry was 15.58% in the 1970's) were selected; then industries whose intrinsic nature does not fit export (those whose export ratio to domestic production is less than 3%) were excluded. Eight industries were selected as the sample for the statistical investigation.

We tried to explain their degree of upstream diversification (U_i) calculated in Table 2 by means of the growth rate in export (E_i), as shown in Fig. 4. The regression equation was $U = -0.038 E + 0.58$ ($R^2 = 0.917$). Thus, upstream diversification is highly related to export growth—that is, the less an industry's growth rate in export is, the larger the industry's degree of upstream diversification. The assumption appears true statistically.

Although there are several arguments, this relation may be one reason why the loss in market does not lead directly to a protectionist movement in Japan; with upstream diversification, employment can be maintained at individual firms. And this upstream diversification can be a strategy for a declining industry to use to keep its competitive edge against newly industrialized countries because it could compensate the loss in final product market by the export of products that are its industrial inputs and by plant engineering.

However, upstream diversification is not a new idea or a new Japanese strategy, as it has been mentioned by Vernon in his "product cycle" work (*13*). Nonetheless, this strategy is supported statistically by the empirical analysis of diversification, described above.

Industrial policy. In the past, the science and technology policy of the Ministry for International Trade and Industry (MITI) was formulated and implemented, not overtly but implicitly, within the framework of industrial policy (*14*). Therefore, we can suppose that the industry's technological diversification behavior can be induced by industrial policy.

As mentioned above, the mechatronic revolution stimulated downstream technological diversification in some industries. Let us look into the development of industrial policy that brought about the mechatronics revolution of the mid-1970's.

Before 1971, two laws to promote electronics and mechanical industries (Law on Temporary Measures for the Development of Machinery Industry enacted in 1956 and Law on Temporary Measures on the Development of Electronics Industry enacted in 1957) had been enforced independently. The main content of these laws was the low interest loan given by semigovernmental financial institutions, such as the Japan Development Bank, to companies for technology development projects, particularly commercialization projects of new technologies.

However, in 1971, these two laws were made into one law, Law on Temporary Measures for the Development of Specified Machinery and Electronics Industries. The mechatronics revolution was clearly envisioned in this law, because expressions such as "consolidation of machinery and electronics into one" or "systematization of them" were used by MITI to explain the objectives of the law in the Diet (*15*).

In 1978, this law was transformed into the Law on Extraordinary Measures for the Development of Specified Machinery and Information Industries; it expired in 1985. Although there are some doubts about how the laws influenced industry behavior, the merger of the two laws at least showed the industries involved where major innovations were to occur in the 1970's.

R&D policy. In Japan, a research association scheme is heavily used as the vehicle for the implementation of the governmental R&D policies (*16*). This is a joint research arrangement of limited duration in which competing firms share researchers and costs and the government provides funds and tax benefits. This scheme was transferred from Britain to Japan and reformulated as the Engineering Research Association (ERA, Kenkyu-Kumiai) in 1961. And, in 1966, MITI launched the National R&D Program (popularly known as the Large-Scale Project). This was the first attempt by MITI to finance 100% of the cost of R&D carried out by private enterprise. Until 1970, the ERA scheme was not used as a vehicle for implementing the Large-Scale Project. However, when it was seen that the Large-Scale Project is compatible with the ERA scheme and that they compensate each other in some kinds of research, then it became normal practice to use ERA for the implementation of the MITI's R&D programs (*17*).

Until 1983, 64 ERA's were established and 45 of them are currently in operation. In the government subsidy program, implemented through the research associations, there seem to be various types of built-in mechanisms to accelerate technological diversification of firms that participate in an association.

One mechanism is concerned with venturism. In Japan, unlike the United States, ventures are in-house as a rule. Not too long ago, I proposed that ERA's were being used by big Japanese firms as springboards into in-house ventures. It is standard practice for a participating firm to set up an in-house project team that has roughly the same number of members as the research team that the firm sends to take part in the joint research. The project team supports the colleagues on assignment, and it also assimilates the data generated by the ERA. As I see it, the project team can be considered as a sort of in-house venture unit. When the ERA eventually disbands and the colleagues on assignment return to the company and add their weight to the project team, the team serves, in effect, as the headquarters of a venture capital business (*18*). Indeed, the choice of a research subject of an ERA is often related to the marginal product fields of participating firms so that it causes less conflicts of interest among them (*19*).

As far as the direction of diversification is concerned, we can derive some lessons from the experiences of the Very Large Scale Integration (VLSI) Project (*17*). In this ERA, in which all the participating firms made computer chips, development centered on how to manufacture the equipment for making chips and on the research in the crystallization process of the silicon, not on how to manufacture the chips themselves. The ERA may be interpreted as a forum for users of manufacturing equipment and silicon crystals to determine together what sorts of manufacturing devices and materials should be developed. In fact, many of the development projects were subcontracted to supply companies in various industries, none of which were members of the association. Thus, this joint research led to the creation of several equipment manufacturers and crystal suppliers and the entrance of existing firms into those product fields and thus helped to build an engineering infrastructure of VLSI manufacturing in Japan.

Conclusion

The direction of technological diversification for each industry has been identified quantitatively from our database. However, there are two possible interpretations. If the distribution of R&D expenditures reflects the innovation-producing pattern intrinsic to each industry, then the direction of diversification identified can be interpreted as a sectoral pattern of innovation. If the distribution of R&D expenditures reflects the future metamorphosis of each industry, the directions identified can be interpreted as the sectoral pattern of industrial transformation.

It is not possible to describe anything about individual firm behaviors in technological diversification. The R&D statistical data, at the level of disaggregation used in this article, are not available on an individual company basis; they are confidential. Thus, quantitative analysis of technological diversification is feasible only for sectors. Several case studies of the diversification behaviors of individual companies are needed to elucidate the directions identified here from aggregate data.

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Japanese Research and Technology Policy

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Until recently the Japanese did not spend much on research and what they did spend was concentrated on the commercial development of technology. As a result there have so far been few Japanese breakthroughs in either science or technology. Dramatic changes have recently occurred, however, and Japan now trails only the United States and the Soviet Union in research spending. Beyond this, Japanese policy-makers are making a determined effort to overcome Japan's social and institutional barriers to scientific creativity.

JAPANESE SCIENCE AND TECHNOLOGY HAS TAKEN ON A PARAdoxical image in the West. There is a growing fear of Japan as a technological juggernaut mowing down foreign rivals at will. And yet, many people (including many Japanese) continue to have doubts about the Japanese ability to create new technology.

One reason for this confused image is that although Japan is now a major technological power, spending more on research and development than any but the two superpowers, this is a recent phenomenon. Thus the relative scarcity of major technological breakthroughs that can be attributed to the Japanese. Two decades ago the Japanese research effort was far below that of the major Western countries. In 1965, for example, the Japanese spent less than 6% as much as the Americans on R&D, only about half as much as the British, and far less than either the French or the West Germans (*1*). By 1970 Japanese R&D spending had passed the British and French, and by 1980 it had passed the West German. In the United States, R&D spending remains substantially higher, but primarily only to the extent that the U.S. economy is larger. In 1982 the United States spent 2.61% of its gross national product (GNP) on research, compared to 2.44% for Japan. Much of the U.S. spending, however, whereas hardly any of the Japanese, was defense-related with little spillover value for the civilian economy. In 1982 the ratio of civilian R&D expenditures to gross national product was 2.43% for Japan compared to only 2.01% for the United States (*2*).

The results of Japan's increased investment in technology are reflected in several indicators. The number of Japanese patents granted to Japanese has tripled since the mid-1960's; for comparison, the number of U.S. patents granted to Americans has stagnated. Meanwhile the Japanese have assumed a commanding lead among foreigners patenting in the United States (*3*). Japanese technical managers responding to a survey in the early 1980's rated their companies as being ahead of the Europeans and only a little behind the Americans in the number of technologies in which they led. A survey published in 1985 found that more managers felt that the technological level of Japanese industry led that of U.S industry than vice versa, and virtually none felt that the United States would

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