The organization and geography of Japanese R&D: results from a survey of Japanese electronics and biotechnology firms

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The paper reports the results of a mail survey of and personal interviews with R&D managers of the largest Japanese electronics and biotechnology firms regarding the organizational and geographic dimensions of their R&D activities. The results indicate that the importance of multi-functional teams for Japanese R&D has been overemphasized. The transfer of employees between R&D and manufacturing and joint meetings are judged as being the most important factors in ensuring the information transfer between the two corporate functions. The findings indicate that basic research facilities have significant locational flexibility. However, applied research and production engineering need to be in close proximity to manufacturing. The differences between the electronics and biotechnology industries were only rarely significant.

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Introduction

The once common perception of Japan as a technological imitator has faded. Similarly, the old view that Japan's technological and industrial success is a function of State targeting and government R&D funding is giving way to a revisionist perspective which places greater explanatory power on the role of firms, corporate organization and business strategy [3]. According to a wide range of studies, Japan has become a global technology leader both in terms of R&D inputs and outputs [1,30,57,64]. In 1989, for example, the top ten Japanese electronics firms spent $15.3 billion on R&D, compared to $12.2 billion for the top ten US electronics companies [16]. Frame and Narin [26, p. 455] concluded that "the patent data clearly show a major tilting of the technological balance away from the United States and toward Japan." The emergence of Japan as an industrial power and technological leader has caused scholars from a variety of disciplines to begin to reconsider the innovation process and the organizational conditions under which innovations are efficiently transformed into commercial products (see [4,5,23,24,36,37,41]).

Traditionally, studies of Japanese innovation emphasized the role of the State, in particular the Japanese Ministry of International Trade and Industry in organizing, promoting and financing

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Japanese innovation [2,9,27,28]. While government targeting and R&D funding clearly had impacts in certain industrial sectors, many of the industries in which Japanese firms have become global competitors are ones in which government intervention has been relatively limited and certainly insufficient to explain rapid technological and industrial growth.

A number of theories have been advanced to challenge this 'strong State' view. From the perspective of industrial organization economics, Mansfield [50] argued that at least part of the reason for Japan's technological success is determined by the allocation of resources and effort at the firm level. In a comparison of a sample of Japanese and US firms, Mansfield found that Japanese firms devoted a greater percentage of their innovation expenditures to tooling and manufacturing equipment than US firms. He further concluded that Japanese firms are advantaged in terms of "carrying out innovations based on external technology, [but] do not seem to have any in carrying innovations based on internal technology" [50, p. 1167].

An important research stream has identified organizational factors as playing a central role in Japan's technological and industrial performance. This work suggests that Japanese industry has organized strong linkages among R&D, product development and manufacturing which allow for the rapid transfer of innovation from the laboratory into production and ultimately to the marketplace. Basically, this view emphasizes the economic and technical efficiencies that come from collaborative problem-solving and organizational learning. Imai et al. [37] highlighted the close integration of R&D, product development and manufacturing activities in Japanese firms (also Hull et al. [35]). Aoki and Rosenberg [5] and Hayes et al. [31] contrasted Japan's integrated approach to R&D and product development with the linear model of large US and European corporations. Case studies by Westney and Sakakibara [68] and a broader survey of Japanese and US engineers by Lynn et al. [44] found that Japanese engineers communicated more frequently with manufacturing than did their American counterparts. In addition, Japanese engineers and researchers were more likely to have experience on the shop-floor than in the US [52]. However, others suggested that problems can arise if R&D is too closely linked to manufacturing, such as the development of a troubleshooting orientation and the consequent neglect of longer-term development of new technologies [39].

A more recent body of research has focused on the role of geographic proximity in the organization of R&D both in the US and Japan. Jaffe [38] suggested that co-location of university and industrial R&D in the US has a significant payoff in terms of the productivity of innovation. Krugman [42] made a strong case for the role of geographic specialization in economic development. Arthur [6,7] and David [12,13] noted that the location of industrial activity, particularly innovative industrial activity, is in large measure historically determined and 'path-dependent.' The geography literature has further suggested that Japanese industry is characterized by significantly greater physical proximity and co-location among R&D, product development and manufacturing than is the case in the US or Europe [23,24,61].

Economic geographers have long noted the geographic specialization of industrial activity, arguing that the innovation process is characterized by a distinct 'spatial division of labor' which allocates different corporate functions, e.g. research laboratories and factories, to different locations (see Walker [67] for a review). Further, R&D activities have themselves been subdivided by type and focus of activity, e.g. into basic R&D laboratories, divisional and applied research laboratories, and product and process development facilities. This division of labor made it possible in the US, for example, to disperse these activities geographically according to workforce characteristics, skill levels, and wage rates (see [49]). Empirical research has indicated that in both the US and Europe corporate headquarters and central R&D laboratories are distinguished by a similar set of location factors, such as high quality human capital, well-developed transportation systems, and urban amenities [33,46,47,49]. This is frequently attributed to the agglomeration economies of large metropolitan areas.

Recent geographic research has noted the decentralization of R&D activity, as both US and European corporations established technical branch plants outside major manufacturing regions, such as Motorola's semiconductor complex in Phoenix Arizona. In addition, economic geographers and regional scientists have argued that 'regional innovation complexes' such as Silicon Valley, California and the Route 128 complex around Boston and Cambridge, Massachusetts comprise an alternative model for the organization of innovation consisting of integrated networks of high-technology firms; large concentrations of high-technology entrepreneurs, managers, engineers and scientists; venture capital funds; and related support institutions ([18,22–24,63]).

While there are a wealth of Japanese-language studies on the location of Japanese R&D, only recently has there emerged an English-language literature on the location of Japanese R&D. Nishioka and Takeuchi [54] found that 90% of the national government's researchers, 60% of the independent research institutes and 50% of those affiliated private entities are located in the Tokyo area. It has been further argued that the requirements of 'just-in-time' production inform a tight integration and co-location of R&D and manufacturing [24,61]. Japanese geographers have pointed out that rapid economic growth and the limited availability of land in major metropolitan centers have brought about pressure for the decentralization of Japanese manufacturing and R&D activities [51]. This trend is reinforced by the increasing globalization of Japanese manufacturing in Asia, the US, and Europe and the demands for dispersed R&D and product development to support these activities [14,25,41].

The research presented here enables us to explore the major issues in the organization and geography of Japanese R&D, such as communication, information flow, and technology transfer as well as organizational linkages among R&D, product development, manufacturing and other corporate functions. We also explore geographic factors at work in the location of different types of Japanese R&D, and the degree of proximity among R&D and other corporate functions and activities.

The research is informed by a theoretical perspective which emphasizes the role of information and knowledge in technology development and transfer. We start from the idea that different types of knowledge or information require different organizational linkages and/or levels of geographic proximity to transfer effectively. Clark and Fujimoto [10, p. 332] point out that "notwithstanding the popular argument that electronic telecommunications media will substitute for face-to-face contact, interpersonal communication will continue to be critical to new product success." In our view, this will be especially true, because knowledge and new ideas are highly tacit, imprecise, and require iteration or trial-and-error to be put into practice. Aoki [4] and Nonaka [55] conceptualize the Japanese firm in terms of information processing and knowledge-creating capabilities. Essentially, we hypothesize that nature of organizational and geographic linkages among various functions of the Japanese firm will depend upon the different types of knowledge creation and information transfer required for the functioning and integration of those activities.

We examine these issues through a survey of R&D organization in the 112 largest electronics and biotechnology companies in Japan. A commonly recognized weakness in the existing literature is its reliance upon generalizations drawn from a limited number of case studies or anecdotal accounts. Our research was designed to overcome this weakness by conducting a survey of the largest R&D-intensive Japanese firms in the 'high-technology' industrial sectors of electronics and biotechnology. The survey research was supported by follow-up interviews and site visits to a representative sample of survey respondents. Together, the two phases of the research explored the nature of the linkages between R&D, product development, manufacturing and other functional units of the Japanese firms, and the main factors in the location of R&D and product development facilities.

Research design

The research was comprised of both survey research and personal interviews. The survey was conducted in 1991 and included the 112 largest Japanese electronics and biotechnology firms. The survey population was defined to include large firms with significant R&D efforts in important and fast-growing high-technology fields. The electronics firms were the largest ones listed in the *1988 Japan Company Handbook* [65] in the following categories: heavy electrical machinery (e.g. Hitachi, Toshiba and Mitsubishi Electric), communications equipment (e.g. Omron Tateisi, NEC

Table 1
Scope of R&D activities

Category	Total mean	median	$N=$	Electronics mean	median	$N=$	Biotechnology mean	median	$N=$
Total scientists and engineers [a]	1973	800	53	3330	1300	26	667	492	27
Basic R&D scientists	114	50	41	172	65	20	60	40	21
Applied R&D scientists/engineers	301	220	41	362	300	20	243	200	21
Product development scientists/engineers	914	378	45	1563	550	21	347	275	24
R&D/sales ratio	7.7%	5.1%	50	6.5%	6.0%	25	9.0%	5.0%	25
No. basic R&D facilities	1.8	1.0	48	2.3	2.0	22	1.3	1.0	26
No. applied R&D facilities	3.6	2.5	48	4.0	3.0	22	3.3	2.0	26
No. product development	5.5	4.0	52	7.3	6.0	25	3.8	3.0	27

[a] The total number of scientists and engineers does not equal the sum of basic, applied and product development personnel since some companies did not provide detailed breakdowns of their R&D personnel.
Source: M. Kenney and R. Florida, Japanese R&D Survey (1991).

and Fujitsu), consumer electronics and parts (e.g. Matsushita Electric, Sony and Sanyo Electric), measuring instruments (e.g. Yokogawa Electric and Avantest), miscellaneous electric and precision machinery (e.g. Canon, Konica, Nikon, Casio, Seiko Epson, and Minolta). Precision machinery was added to the electronics group because those companies are now important competitors in the electronics industry. The sample population of biotechnology firms was drawn from the Japanese Biotechnology Industry Centre (BIDEC [8]) directory of member companies. In using the BIDEC directory we chose to omit all of the non-industrial members such as construction companies, banks and brokerage houses. The addresses were obtained from the *Japan Company Handbook*. The companies included were from the pharmaceutical, chemical, food and beverage processing industries.

The survey instrument obtained information on the organization of R&D, linkage and communication between R&D and other units of the firm, and the main factors in the location of R&D facilities. It was designed in English and then translated into Japanese; this translation was then checked by two Japanese professors for wording and meaning. The survey employed standard definitions of R&D activity used by both the U.S. National Science Foundation and the Japanese government, e.g., basic research, applied research and development. [1] We recognize, however, that even such 'standardized terms' can be interpreted differently in the two countries and by different respondents (see [32,59]).

The survey was implemented in two stages: an initial mailing and a follow-up (see Dillman [15] for a discussion of survey design and implementation). Both mailings consisted of a letter of introduction in Japanese outlining the purpose of the survey, a brief biography of the two principal investigators, the Japanese-language survey printed in booklet form, and a stamped self-addressed envelope. The surveys were addressed to the 'R&D Planning Section' of each firm. The initial mailing achieved a response rate of 32% (36, $n = 112$). The second mailing increased the total response rate to 48% (54, $n = 112$). The response was divided evenly between the two

[1] Basic research was defined as "research undertaken primarily for the advancement of scientific knowledge, where specific practical application is indirectly sought." Applied research was defined as "research undertaken primarily for the advancement of scientific knowledge, with a specific practical application sought directly." Product development was defined as "the use of available knowledge obtained as the result of basic or applied research and/or practical experience which is directed to the introduction of new materials, equipment, products, systems and processes, etc. or the improvement of such already made available." (See Papadakis [59] and Hicks and Hirooka [32] for discussions of the meaning of 'basic' research in the US and Japan.)

industry subgroups with 27 reponses for electronics and biotechnology respectively.

The survey responses exhibited some bias toward the largest and most R&D intensive firms. Only two of Japan's largest electronics firms (e.g. Toshiba Corporation and Hitachi Ltd.) declined to participate. Most of the largest firms in the Japanese biotechnology firms responded. In other words, the respondents comprise the largest R&D investors and R&D employers in the Japanese electronics and biotechnology industries. The persons completing the survey came from different parts of the firm including: corporate R&D, the planning section, and engineering administration. There was no systematic bias by geographic location.

Follow-up field research and personal interviews were conducted with a representative sample of survey respondents to gain more detailed information on the organizational and geographic dimensions of R&D. Managers of 23 firms were interviewed in Tokyo, Osaka and Kyoto. The interviews took on average 1–2 hours each and were comprised of both structured and unstructured questions. The interviews collected further information on the organization of R&D, modes of linkage between R&D and other corporate functions, and the main locational factors which influence Japanese R&D.

Organization of R&D

Scope of R&D activities

Basic data on the scope of R&D activities for respondent firms is provided in Table 1, including the total number and functional breakdown of research scientists and engineers, the R&D to sales ratio, and the number of various types of R&D facilities (e.g. basic or central, applied and product development). Generally speaking, the results indicate that the respondent firms evidence a significant degree of R&D intensity. Overall, the respondent firms average 1973 R&D scientists and engineers, the median number being 800 ($n = 53$). The distribution was skewed by industry. Electronics firms averaged 3330 R&D scientists and engineers (median 1300, $n = 26$) compared to biotechnology firms with a mean of 667 and a median of 492 ($n = 27$). It should be noted that one respondent firm reported over 16000 R&D personnel. As might be expected, the majority of R&D scientists and engineers were focused on product development activities (mean 914, median 378), with significantly fewer on average in applied R&D (mean 301, median 220), and basic or central R&D activities (mean 114, median 41). Electronics firms led biotechnology firms across all categories.

The ratio of R&D to sales is a commonly used measure of R&D intensity. On this measure, the respondent firms are significantly R&D intensive. The average R&D to sales ratio for the respondent group was 7.7% (median 5.1%). The biotechnology firms devoted a larger share of sales to R&D (mean 9%, median 5%) than the electronics firms (mean 6.5%, median 6%). The respondent firms also had a significant number of R&D facilities, averaging 5.5 product development facilities, 3.6 applied R&D facilities, and 1.8 basic R&D laboratories each. The electronics firms again led biotechnology firms on each dimension.

Table 2
Mechanisms for linking R&D and manufacturing

Mechanism	Overall	Electronics	Biotechnology	$N=$
Transfer of employees from R&D to manufacturing	4.02	4.11	3.92	53
Joint meetings of managers from R&D and manufacturing	3.94	4.07	3.81	53
Multi-functional teams	3.87	3.93	3.82	54
Annual or semi-annual science conferences or technology fairs	3.75	3.74	3.76	54
Transfer of employees from manufacturing to R&D *	3.47	3.82	3.12	54
Requiring manufacturing to finance R&D **	2.78	3.08	2.50	51

* Significant at the 0.05 level; ** Significant at the 0.10 level.
Responses are on a 1–5 scale where 1 is not important and 5 is very important.
Source: M. Kenney and R. Florida, Japanese R&D Survey (1991).

Linkages between R&D and manufacturing

As noted above, the research literature suggests that Japanese corporations are characterized by strong linkages between R&D and manufacturing. The literature has suggested various mechanisms for facilitating such linkage including the use of multi-functional teams, rotation and transfer of R&D personnel to manufacturing units, the use of meetings and informal contacts to connect the two groups, and financial incentives such as having operating divisions rather than corporate headquarters finance R&D activities (see Aoki [4]).

Table 2 reports the findings on the mechanisms used to link R&D to manufacturing. The findings here shed important light on a number of issues. The transfer of employees from R&D and manufacturing was seen to be the most important mechanism for fostering linkages between R&D and manufacturing with a score of 4.02. This was true of the survey respondents as whole as well as for each of the two industries. Interestingly, while 'reverse' transfers from manufacturing to R&D were of significant importance to the electronics companies, they were of less importance to biotechnology firms. An R&D manager who was interviewed at a major Japanese optical products/camera company succinctly summarized the motivations and incentives that encourage R&D personnel to participate in such transfers:

> Develop a product first in R&D and get a patent on it. Then you take the lead in transferring that product to a manufacturing site. It does not matter how good the prototype products you have made are unless you make that transfer successful, you would not be considered very good. And if the product sells well in the market and creates profits you will likely become the leader of a business group. The leader of business group can be a managing director (the lowest level of executive).

Not all firms in the sample engaged in transfers or rotations between manufacturing and R&D. A major electronics firm in the sample noted that it wished to transfer an entire development group to a manufacturing plant in Kyushu. However, nearly half of this group of 60 R&D personnel refused such transfer, and left the company to take jobs with other firms. Other firms in the sample did not attempt to transfer R&D scientists and engineers to other corporate functions. For example, in an interview the senior managing director of research and development for a major Japanese pharmaceutical company noted that: "There is a rotation within research and development, but not to production." A number of firms in the sample noted that R&D scientists and engineers are reluctant to accept transfers to manufacturing or administrative positions outside the R&D function. An R&D manager at a leading Japanese chemical company stated that:

> When I was asked by the head of the [central] research institute to transfer, I said "No." And then another head of research talked to me and kind of persuaded me, and I understood why I had to go. So there is mutual understanding that it is a good idea to go. It is not against my will. I would like to go back. I used to stay in the central research laboratory which is more research oriented. But now since I moved here, I have found some of the development work at the development research lab at the plant level which is more focused on product development. I found it interesting. And also the business groups may be interesting.

The literature on the Japanese firm has emphasized the importance of communication, information flow and knowledge creation. This position has been advanced by Aoki [3,4] from a microeconomics perspective and Nonaka [55] from the point of view of management strategy. Aoki and Nonaka generalize from the Japanese firm to conceptualize a new model of industrial organization and firm behavior based upon knowledge mobilization and information transfer. The findings of our research lend some support to this view. As Table 2 shows, meetings between R&D and manufacturing personnel ranked second with a score of 3.94. Indeed, meetings (3.94) scored higher than the multi-functional teams (3.87) which the organizational perspective has identified as the most significant mechanisms for organizational integration and linkage. This pattern was particularly evident for electronics firms in the sample, where the scores were 4.07 versus 3.81. We included a response category for annual

Table 3
Problems encountered in linking R&D and manufacturing

Problem area	Overall	Electronics	Biotechnology	$N=$
Ensuring adequate communication between R&D and manufacturing	4.37	4.52	4.22	54
Convincing researchers of importance of manufacturing *	4.06	4.26	3.85	54
Convincing manufacturing of the importance of R&D	3.87	3.91	3.84	54

Responses are on a 1–5 scale where 1 is not important and 5 is very important.
* Significant at the 0.10 level.
Source: M. Kenney and R. Florida, Japanese R&D Survey (1991).

or semi-annual corporate conventions or science fairs which many Japanese companies use. This ranked third from last with a score of 3.75. The use of financial incentives ranked last (2.78), significantly behind the other factors, suggesting that such incentives are perceived to be of limited utility. However, some of the very largest companies mentioned using 'internal contracting' in their responses and in the follow-on interviews. The findings here tend to reinforce the informational perspective of Nonaka and Aoki on the Japanese firm, while contradicting the organizational perspective's claim that multi-functional teams comprise the 'heart' of the linkage between R&D and manufacturing.

Connecting R&D functions to manufacturing is a difficult organizational problem for firms, particularly for large multinational corporations. Indeed, there is a huge literature detailing the problems large US and European companies encounter in linking R&D and production activities (see Florida and Kenney [23] for a review). The survey included a question designed to identify the obstacles Japanese firms encounter in connecting innovation and production activities. The question was phrased as follows: "What are the main problems you face in linking manufacturing and R&D?" The relevant findings for this question are presented in Table 3. As this table shows, the survey respondents identified "ensuring adequate communication between R&D and manufacturing" as the main problem area. This scored 4.37 on a 5-point Likert scale running from not important to very important. This was followed by the response: "convincing researchers of the importance of manufacturing" which scored 4.06; and "convincing manufacturing of the importance of R&D" which scored 3.87. Interestingly, the only statistically significant difference (at the 0.1 level) was that electronics respondents found it not important to convince researchers of the importance of manufacturing. Part of the explanation here may be that manufacturing is more important to overall corporate performance in the electronics industry than it is in the biotechnology sector, therefore it receives greater attention from researchers and corporate managers.

Linkages between R&D and corporate functions

Linkages among R&D and other corporate units in addition to manufacturing, e.g. marketing and headquarters have also been identified as important aspects of R&D organization. Malecki [46] found that 88% of US firms have their R&D and administrative facilities located in the same metropolitan area. Howells [33,34] found that British firms link R&D to headquarters. The literature on Japanese industry suggests that there are tight linkages between manufacturing and

Table 4
Relative difficulty of linking R&D to other corporate functions

Linkage	Overall	Electronics	Biotechnology	$N=$
Between R&D and marketing	3.21	3.31	3.11	53
Between R&D and manufacturing	2.46	2.59	2.32	54
Between headquarters and manufacturing	2.36	2.35	2.37	53
Between R&D and headquarters	2.33	2.37	2.30	54

Responses are on a 1–5 scale where 1 is very easy, and 5 is very difficult.
Source: M. Kenney and R. Florida, Japanese R&D Survey (1991).

R&D [58]. However, less attention has been paid to R&D's linkage with other corporate functions such as headquarters and marketing.

The survey results with regard to the difficulty of achieving organizational linkages among R&D and other corporate functions are outlined in Table 4. Quite interestingly, the survey respondents indicated that linkages between R&D and marketing were the most difficult. This was seen to be significantly more difficult than linking R&D to either manufacturing or headquarters. This was true in both the electronics and biotechnology industries. The reason for this may be the strong 'production' orientation of many Japanese firms. A Japanese R&D manager stated that to overcome this problem the firm should rotate personnel from sales to R&D rather than the current policy of one-way rotation from R&D to sales. He further noted that this might bring more knowledge of the marketplace and new ideas to R&D. Survey respondents viewed linkages between headquarters and other corporate functions including R&D and manufacturing as the least difficult to achieve.

The follow-up interviews with survey respondents indicated that the relationship between R&D and manufacturing has benefits which extend beyond rapid cycle times. Japanese R&D facilities often play an important role in the development of highly sophisticated tools and manufacturing equipment. For example, the R&D section of a medium-sized Japanese electric instruments company in our sample provided in-house design of automated assembly equipment. The production engineering laboratory of Matsushita Electric Industries developed Panasert component insertion machines and robot assembly equipment for internal use. Now this equipment is sold to non-Matushita electronics firms and generates $1.5 billion in annual revenues. Furthermore, Japanese semiconductor laboratories and product engineering centers design, develop and initially even produce the manufacturing equipment required for etching, measurement, particle and impurity control, diffusion and lithography. Mitsubishi Electric and Hitachi's Basic Laboratories cooperate with the production facilities in the development of sophisticated manufacturing equipment. The technology used in this equipment is at the cutting edge of fields such as surface science, chemistry and applied physics.

Relationship between basic and applied R&D

There is relatively little research on the relationship between basic and applied R&D in Japanese industry. Most Japanese firms have relatively large central R&D laboratories which conduct a wide range of research in various scientific and applied disciplines, as well as distributed applied R&D facilities and product development centers which are more closely tied to production activities. The survey asked a series of questions designed to examine the linkages between basic and applied R&D. The main factors which Japanese firms use to link basic and applied R&D activities are summarized in Table 5. As this table shows, survey respondents ranked the transfer of personnel as the most important mechanism for connecting these basic and applied R&D activities. This was true for both the electronics and biotechnology firms. However, such transfers were ranked significantly higher by electronics industry respondents. Again, regular meetings (3.96) scored higher than multi-functional teams (3.88). This difference is entirely attributable to the biotechnology respondents in

Table 5
Mechanisms for linking basic and applied research

Mechanism	Overall	Electronics	Biotechnology	$N=$
Transfer of employees from basic to applied research *	4.12	4.38	3.88	49
Joint meetings of managers from basic and applied research	3.96	4.00	3.92	49
Multi-functional teams	3.88	4.00	3.76	49
Transfer of employees from applied to basic research	3.71	3.79	3.64	49
Annual (or more frequent) corporate technology conventions	3.47	3.71	3.24	49

Responses are on a 1–5 scale where 1 is not important and 5 is very important.
* Significant at the 0.01 level.
Source: M. Kenney and R. Florida, Japanese R&D Survey (1991).

the sample, as electronics industry respondents gave meetings and multi-functional teams the same score (4.00). 'Reverse' transfer of employees from applied R&D to basic R&D facilities ranked fourth (3.71). Corporate-wide technology seminars or conventions ranked last (3.47). In general, electronics firms rated the various mechanisms consistently higher than did the biotechnology firms. While it is impossible to entirely discern the reasons for this response pattern, it may be due to the fact that 'speed to market' is more important in electronics than biotechnology.

The survey also identified the main problem areas confronted in linking basic and applied R&D. The results are summarized in Table 6. Overall, the major problem identified was 'promoting respect between these two different groups" which scored 3.18. This was followed closely by "different methods of problem solving" which scored 3.12. Promoting good communication between the two was seen as less problematic. Generally speaking, the biotechnology respondents indicated greater difficulty in connecting basic and applied research than the electronics industry respondents. This finding can be viewed in light of the results presented in Table 5 which indicate that electronics industry respondents consistently ranked various mechanisms for linking basic and applied research higher than their counterparts in the biotechnology industry. It may well be that the emphasis placed on linking basic and applied R&D by the electronics industry respondents actually translates into less problematic linkage patterns. While the data point to such a relationship, they do not allow us to directly test for this result. A potential explanation for this pattern lies in the different underlying scientific and technological bases of the two sectors, with biotechnology research being more closely connected to basic science. In an interview, the senior managing director of R&D for a major Japanese pharmaceutical firm noted that the company hires scientifically oriented basic researchers to deepen its biotechnology program. While these scientific researchers tried to understand the underlying biological mechanisms for pharmacological applications, applied scientists were satisfied with knowing that it worked. Their different approaches to problems led to difficulties in communication, interaction and linkage.

Field research at other firms in the sample indicated that basic and applied R&D tend to be linked through common objectives. All of the interviewees noted that basic research projects were 'goal-oriented,' meaning that such projects were focused on commercial applications. They further indicated that Japanese companies did not possess the resources to do the basic research of the sort conducted by universities, IBM Yorktown Heights and AT&T Bell Laboratories. The firms in our sample noted that there were only two real exceptions to this pattern among Japanese corporations–Hitachi which founded a laboratory aimed at conducting Nobel Prize-level basic research and Mitsubishi Chemical's Life Science Research Institute whose aim is to explore the frontiers of life science. However, respondent firms indicated that basic research activities tend to improve corporate image and make recruiting easier, even when there is no immediate commercial payoff.

Geographic organization of Japanese R&D

Generally, Japanese R&D facilities are concentrated in the Tokyo and the Tsukuba 'Science City' in Ibaraki prefecture which was launched by the national government to encourage the decen-

Table 6
Problems in linking basic and applied research

Problem	Overall	Electronics	Biotechnology	N =
Promoting respect between these two different groups *	3.18	2.84	3.52	50
Different methods of problem-solving *	3.12	2.84	3.40	50
Promoting good communication between the two groups	2.80	2.60	3.00	50

Responses are on a 1–5 scale where 1 is not important, and 5 is very important.
* Significant at the 0.05 confidence level.
Source: M. Kenney and R. Florida, Japanese R&D Survey (1991).

tralization of R&D from Tokyo. As mentioned earlier, a large percentage of Japanese researchers are located in the Tokyo area. In addition, 30% of the universities and colleges of technology are also in the Tokyo area. This is far more concentrated than in the US. According to Malecki [45], the Boston–New York–Washington megalopolis accounts for the largest concentration of industrial laboratories in the US, but this is still less than 40% of all US industrial laboratories. [2] The geographic literature highlight the co-location and proximity between R&D, product development and manufacturing in Japan. This has been linked to the inherent advantages of just-in-time production systems with information flow between end-users and supplier (see, for example, Sayer [61]). Eto [20, p. 156] identifies Hitachi and Mitsubishi Heavy Industries as examples of Japanese companies which have explicitly located R&D close to manufacturing to heighten communication and information transfer. Using the survey results, the following sections probe the geographic aspects of Japanese R&D, in particular the major factors behind the location of basic R&D, applied R&D, and product engineering facilities.

Location of basic R&D

There is a fairly well-developed literature on the location of R&D facilities in the US ([45,48,49]). This literature has found that the location of R&D laboratories is related to factors such as: proximity to universities, availability of scientists and engineers, and so-called 'quality of life' variables. Recent econometric research by Jaffe [38] identifies a strong correlation between the location of university and industry R&D in the United States (see also Feldman [21]). Malecki and Bradbury [49] found that the location of basic R&D in the US is related to the supply (and locational preferences) of scientific and technical workers, and that this is closely related to characteristics of the local labor market, in particular city size and the presence of major research universities. As we have already seen, the literature on Japanese industry identifies a high degree of spatial proximity and clustering of R&D and manufacturing. This literature further suggests that this is due to the tendency for Japanese firms to organize their activities in integrated innovation–production complexes to optimize information transfer, enhance the flow of knowledge and ideas, and rapidly turn innovations into marketable products [4,36,41,55].

The main factors in the location of Japanese R&D labs are reported in Table 7. We begin our analysis with the location factors which affect the location of basic R&D. As Table 7 shows, the highest ranking location factors for basic R&D were as follows: a 'good living environment' (3.98), proximity to universities (3.92), transportation (3.80), availability of engineers (3.67), proximity to government R&D facilities (3.51), and the availability of low cost facilities (3.16). With regard to government R&D facilities, responses were highly skewed, indicating that this was very important to some and not important at all to others. Proximity to other corporate functions and to suppliers ranked much lower. Quite surprisingly, proximity to factory sites ranked third from last, just slightly ahead of the location of competitors' R&D facilities. This response pattern is essentially similar to that identified by Malecki [46,47,49] for US basic R&D, as both appear to be driven by quality of life variables, availability of human capital and transportation.

The follow-up interviews and site visits provide a richer context from which to understand the survey results. In the interviews, it became clear that three factors–'good living environment,' 'good transportation linkages' and 'availability of engineers'–were consistently important. This typically translated into a location in either of Japan's two main metropolitan centers, Tokyo or Osaka, which provide the high level of urban amenities, proximity to other corporate functions, and transportation networks required for basic R&D. This is essentially similar to the locational patterns for basic R&D in both the US and Europe where a consistent 'large city preference' has been identified [34,47,49]. However, it should be pointed out here, that the concept of a 'good living environment' differs in Japan from the West. For example, the major locations for Japanese basic R&D, Tokyo and the Osaka–Kyoto area hardly fit Western conceptions of 'good living environments.'

[2] Calculation is from Table 2 in Malecki [45]. This point is also made in Nishioka [53, p. 5].

Table 7
Major factors in Japanese R&D location

Factor	Basic R&D	Applied R&D	Production Engineering
Close to the factory	2.14	3.46	3.96 *
Close to corporate headquarters	2.28	2.53 *	2.57
Close to basic R&D facilities	–	3.17	2.52
Close to product development facilities	2.56	4.10	–
Close to applied R&D facilities	3.28	–	3.84
Close to universities	3.92	3.00	2.57
Close to government R&D facilities	3.51	1.35 *	2.39
Close to supplier's R&D facility	2.20	2.68	2.77
Close to competitors' R&D facility	2.04	2.02	1.96
Far from competitors' R&D facility	1.98	2.00	1.92
Low cost facilities	3.16	3.25	3.36
Availability of engineers	3.67	3.22	3.77
Good living environment	3.98	3.84	3.79
Good transportation linkages	3.80	3.84	4.10

Responses are on a 1–5 scale where 1 is not important and 5 is very important.
* Significant at the 0.01 confidence level; ** significant at the 0.05 confidence level.
$N = 48–50$ for basic R&D, 50–52 for applied R&D, 52–54 for production engineering.
Source: M. Kenney and R. Florida, Japanese R&D survey (1991).

The follow-up interviews also shed important light on the relationship between university R&D and industrial R&D in Japan. Respondents noted that 'proximity to universities' was basically used as a proxy for location in a major metropolitan area, e.g. Tokyo or Osaka. Some expressly stated that proximity to a university meant having good 'connections' to professors which are required to ensure access to the best students. The general manager of corporate planning at a major computer company, clarified his survey response as follows: "If we [the company and the professor] drink sake together, then through that kind of connection we can get good students. In that sense [of closeness], but it's not the matter of the R&D." The general manager of R&D administration of corporate R&D at a major Japanese chemical and machinery producer, explained that "it is more personal connection than geographical closeness."

The field research and follow-up interviews helped to clarify what was meant by the response 'proximity to government research facilities.' Japanese government research facilities are more important in some areas than in others, thus firms in industrial areas with important government research were more likely to locate their own R&D close to those facilities. Location close to a government research facility was frequently coterminous with location in Tsukuba 'Science City where many government research facilities have been relocated. The general manager of the engineering coordination division of a major Japanese computer company, reported that his company's "new basic research laboratory is located in Tsukuba because it is close to the government research facilities." [3]

As noted above, the least important factor in the location of basic R&D facilities was proximity to competitors' R&D facilities. The follow-up site visits and interviews suggested that the main reason for this is the limited flow of information between competing Japanese firms. This is markedly different in the US where high degrees of clustering or agglomeration of R&D facilities have been identified [48,49]. A general manager of R&D for a major Japanese corporation noted that in Japan, "it is not important to locate the research close to the competitor's lab. But, in the United States it is very different; there are many exchanges of people between the labs. So, [our lab in the U.S.] was located because of the concentrated research around the area."

Our field research further suggested that the location of basic R&D facilities was to a large

[3] The interview was also attended by the senior program manager of the engineering coordination division.

extent historically determined and thus highly 'path-dependent' (see [6,7,13]). The main reason is the tight constraints operating on the location choices of Japanese firms, stemming from the limited availability and high cost of land for new construction in major urban centers. The problem is not merely the price of land; indeed, large tracts are frequently unavailable at any price. The location of basic R&D in Japan is frequently limited to existing land owed by the firm. Thus, Japanese corporations often build R&D facilities on land that may have been formerly occupied by a factory or continues to be shared with a factory. The general manager of a respondent firm noted: "These locations [for R&D facilities] are tied up with history. There is no rational choice involved."

Location of applied R&D

The main factors in the location of applied R&D facilities were significantly different from those for basic R&D. As Table 7 shows, the highest ranking locational factor was proximity to product development facilities which scored 4.10 on a 5-point scale. This was followed by a good living environment (3.84), transportation linkages (3.84), proximity to factory sites (3.46), low cost facilities (3.25), availability of engineers (3.22), proximity to basic R&D labs (3.17), and proximity to universities (3.00). Other factors scored considerably lower. These findings are in line with previous research which suggests that the Japanese just-in-time production system leads to co-location of innovation and production activities.

Location of product development and production engineering

Table 7 also shows the main factors in the location of production engineering and development facilities in Japan. Here, the top-ranked factors were: transportation (4.10), proximity to factory sites (3.96), proximity to applied R&D facilities (3.84), a good living environment (3.79), and availability of engineers (3.77). Each of these factors scored in excess of 3.7 on a 5-point scale. Other factors ranked significantly lower. There was an important difference between electronics and biotechnology industry respondents in the location of product development facilities. Electronics industry respondents ranked location 'close to the factory' as very important (4.52). However, biotechnology respondents gave this a significantly lower score (3.41). Indeed, this was one of a very few variables where the difference of means was significant at the 0.01 level. The follow-up interviews suggested that in the electronics industry construction of new electronics factories is frequently coupled with the construction of new product development facilities and/or an applied research facility. This is in line with Fruin's [29] concept of 'development factories,' which combine elements of product development and manufacturing and whose function is to move production down the learning curve and stabilize the production process for later transfer to peripheral and overseas locations. In the biotechnology industry, however, this was far less likely. Furthermore, biotechnology respondents found it significantly more important (0.01 level) than the electronics respondents to locate both product and process engineering facilities and applied research facilities close to headquarters. This result may also reflect the different scientific and technological bases of the two sectors. Technological advances in biotechnology more closely depend on basic science (see Kenney [40]), while advances in electronics depend closely upon interaction between researchers, engineers and actual production facilities, particularly to increase the yield of complex production processes.

Suppliers and R&D location

Von Hippel [66] noted the importance of close linkages between suppliers and end-users to the innovation process. The literature on Japanese industrial organization emphasizes the close linkages and interaction between suppliers and customers which is characteristic of Japanese just-in-time production (see Dore [17]; Kenney and Florida [41]). Close relationships between end-users and suppliers have frequently been seen as crucial to rapid product development. As Table 7 indicates, the survey respondents indicated that proximity to suppliers is not a significant influence on location. However, the answers here varied according to the type of R&D facility. Proximity to suppliers was relatively more important to the location of product development facilities (2.87), than it was to the location of applied research facilities (2.68), or basic R&D labs (2.00). There was no significant difference between biotechnology and electronics companies on these dimensions. These findings stand in some contrast to the tendency of supplier's plants to cluster in close proximity to an end-user's assembly facility under the just-in-time system of supply and delivery.

However, there are two caveats to these results. First, the literature has tended to focus on supplier end-user relationships in the automobile industry where components are bulkier and more difficult to transport than in the electronics or biotechnology industries. Second, the survey responses are almost exclusively from large end-users who are less constrained in their locational choice than suppliers. In other words, suppliers may tend to locate their R&D facilities in response to end-users' location choices and in close proximity to the R&D units of their major customers. Additional research is required to fully clarify this issue.

Decentralization of Japanese R&D

As noted above, Japanese firms are under pressure to decentralize activities as a result of rapid growth, labor shortage, and escalating land prices in central areas. Matsuhashi and Togashi [51, p. 185] have documented the decentralizing tendency of Japanese industry where branch plants are increasingly located in peripheral areas. However, they note that:

> The decentralizing tendency was not accompanied by the decentralization of final assembly plants, which still [are in] charge of key functions in the production systems of the machinery industry... The large agglomeration of subcontracting firms [is] still in the traditional industrial centers and their outskirts, where R&D functions have also been recently located... Thus, we have to be careful of overestimating the decentralizing tendency. (Matsuhashi and Togashi [51, p. 185])

Kwok's [43] research on the locational determinants of the Japanese semiconductor industry suggests that even though some semiconductor production facilities were located in peripheral areas, others continued to be located in Tokyo to ensure a close linkage with their R&D facilities.

The results of the interviews and site visits at Japanese facilities indicate that Japanese firms have devised strategies to cope with decentralization and avoid the extreme spatial separation of R&D, product development and manufacturing evident among some larger US and European corporations. For example, our field research indicates that Japanese firms often relocate development and production engineering groups to the new manufacturing site. The general manager of the engineering coordination division for a major Japanese electronics company noted:

> In our case, we first moved the manufacturing facility out. We sent some of the engineering also and the engineering grew rather rapidly in that manufacturing plant. Not development, development people remained at the central facility... But as the local manufacturing activities grew, they needed more engineering at the manufacturing plant and they recruited engineers. And the engineers power grew in the plant. We then moved some of the development activity [to the plant].

The manufacturing plant thus functioned as a 'magnet' for engineering and development activity.

Understanding the organization and geography of Japanese R&D

Our findings on the location of Japanese R&D, taken together with the findings on the organization of R&D, shed light on the relationship between knowledge and technology transfer. The main difference between Japanese R&D organization and that typically practiced by US and European firms lies in more applied R&D. In fact, the organization and location of basic R&D by Japanese corporations is quite similar to that of the US and European corporations.

The research findings support the hypothesis that different types of knowledge produced by various corporate functions require different organizational and geographic linkages. The survey results indicate that for Japanese firms in the electronics and biotechnology industries it is the more applied forms of R&D that are closely linked to manufacturing both in terms of organization and geography. This is because developing working prototypes and scaling them up for production involves a continuous transfer of knowledge and skill between engineering and production. Japanese basic R&D, on the other hand, does not evidence quite as tight linkages. Indeed, Japanese basic R&D is located in some degree of isolation from either more applied R&D or manufacturing.

R&D and corporate strategy

Ever since Schumpeter [62], R&D has been seen as a major mechanism of corporate growth. Ergas [19] suggested that Japanese firms invest in R&D both to 'deepen' their capabilities in existing industries and to 'shift' into emerging technological fields. According to Clark [11, p. 63]: "it could even be said that Japanese firms research their way out of stagnation. ... Slow though it is, the Japanese mode of diversification preserves both the social and technical coherence of the firm." While both US and European companies tend to cut back R&D spending during business cycle downturns, Japanese companies try to grow across the valley' increasing R&D and other investments steadily during slowdowns.

The role of R&D in corporate strategy goes well beyond simple expenditures. R&D can be used to create new technologies and whole new lines of business. Imai [36] has observed that to maintain the rapid pace of new product introductions Japanese companies frequently have two or more teams working simultaneously at different stages of the product cycle. Thus, as the first product is entering the market, a second team is already prototyping the next generation product. In this way, new product introduction is constant and both changes in market demand and technological improvements are rapidly incorporated into new product generations.

It has commonly been observed that R&D is a weapon to penetrate new fields. Japanese R&D managers of firms in our sample indicated that they are increasingly called upon to develop new products. As Japanese firms have moved to the forefront of global competition, they have moved significantly beyond technology that is available from foreign sources. Furthermore and contrary to both common perceptions and the practice of large US and European corporations, many Japanese firms in our sample viewed technology sales as undesirable. The senior associate manager of the corporate planning department of a major Japanese opto-electronics company observed that it was necessary to increase the R&D investment from 6% of sales currently to 10 or 15% over the next two decades because the company could no longer purchase technology from other firms:

> Such technology does not exist. How can we do it? All I know is that in cameras, office copiers and fax machines, only a Japanese company can make a high level product. So if a company wants some technology they must license from another company. Each company is a competitor so the company would become dependent upon its competitor's policies.

Aoki [3] has noted that Japanese firms are particularly adept at technological incubation and spin-off, and that they are able to benefit by retaining close organizational and social ties to spin-off enterprises. Our findings lend support to this concept of technological diversification via spin-offs of corporate affiliates. The general manager of the corporate R&D strategy department of a major optical and precision machinery company in our sample, noted that R&D expenditures as a percentage of sales "increase every year. The reason is that manufacturing divisions are becoming subsidiaries–sales divisions are also becoming subsidiaries." Our interviews further suggest that Japanese firms are able to efficiently exploit their core technologies and technological competencies to enter new business areas. For example, the senior associate manager of the corporate planning department at a photographic products and precision instruments firm outlined the company's efforts to enter the cassette tape market dominated by Sony, TDK, and Hitachi Maxell. The company did so by exploiting its existing expertise in surface chemistry and coating for photographic film, applying it to magnetic tape development and production. The same was true in the biotechnology sector. The deputy general manager of the patent department for a major dairy products company summarized his company's strategy for entering the pharmaceutical business:

> Our company had much accumulation of knowledge concerning nutrition. And another

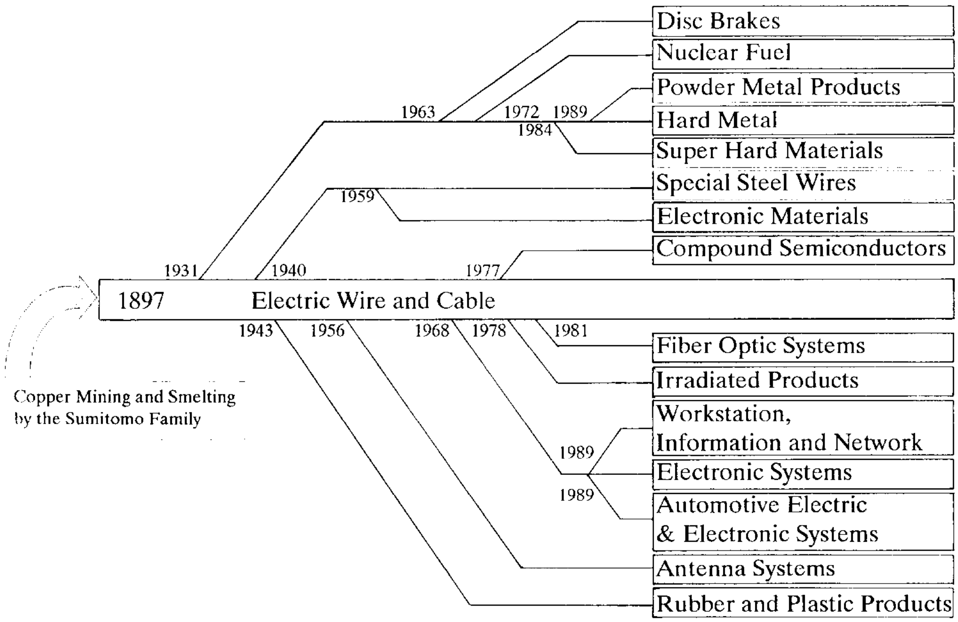

Fig. 1. The R&D driven diversification of Sumitomo Electric Industries (Sumitomo Electric Industries Co., 1991).

reason is we are producing cheese and yogurt so we have many microbiologists. So it is easy to enter into pharmaceuticals such as antibiotics. So at our research institute we started researching antibiotics.... And the third reason is we have many veterinary scientists who could be transferred to working on humans.

To understand this process of growth through related diversification, Fig. 1 illustrates the historical growth and diversification of Sumitomo Electric Industries compiled from our field research on this firm. Most of these diversifications were made possible by new developments by Sumitomo's R&D Laboratories. The company's original core business in the late nineteenth century was copper mining and smelting. During the early part of the twentieth century Sumitomo Electric used its skills in smelting to move its business focus progressively into copper wire manufacture. In the immediate postwar era the company drew upon its technological base in metals and wire to move into special steel wires, in wire coatings to move into rubber and plastic products, and in electronics to move into electronic materials and antenna systems. By the 1960s, the company moved into progressively more complex systems technologies such as integrated electronics systems and disc brakes. In the 1970s and 1980s, Sumitomo used its built up technological competencies to move into high-technology electronic systems (e.g. workstations) and automotive electrical systems. At each stage in its development, Sumitomo leveraged internal technological capabilities developed through R&D to underpin diversification and growth by entering new fields.

Our field research clearly suggests that Japanese firms are able to use both new and existing R&D resources strategically to develop new commercial technologies and enter new business areas. They are particularly adept at using their existing technological capabilities and competencies to enter new technology-intensive, high-growth fields and to create new spin-off firms as part of their corporate galaxy of affiliated companies. In doing so, they have developed a powerful institutional capability to engage in the process of technological transformation which Schumpeter [63] referred to as 'creative destruction.'

Summary and discussion

The empirical findings of the research support some aspects of the literature and the conventional wisdom on Japanese R&D, contradict others, and provide some new insights on the organization and geography of R&D and innovation.

First, the findings contradict a major theme which runs through both the academic literature and the conventional wisdom on Japanese R&D and industrial organization, the role and importance of multi-functional teams. Our survey results indicate that such multi-functional teams are significantly less important in connecting R&D to manufacturing and other corporate functions than the extant literature suggests. The movement of people from R&D to manufacturing and other corporate functions is the single most important mechanism for organizational linkage. The survey findings further indicate that conventional meetings are more important than multi-functional teams in achieving organizational integration among R&D, product development and manufacturing. Similarly, our findings offer little support for a simple 'financial incentives' model of Japanese R&D and manufacturing. The survey results indicate that the use of financial incentives, such as having manufacturing pay for R&D directly, are perceived to be among the least effective mechanisms for achieving organizational linkage and integration.

Second, our findings lend support to the informational perspective on the Japanese firm associated with Aoki [3,4], Nonaka [55] and Imai [36,37]. The importance of meetings and other types of communication reinforce the conceptualization of the Japanese firm as a vehicle for effective knowledge creation, information transfer, and communication. While our empirical results are far from conclusive on this point, they are encouraging.

Third, our findings suggest that R&D and other corporate activities must be 'unbundled' to fully understand their organizational and geographic dimensions. Different types of R&D are organized and located according to different criteria. Proximity to manufacturing matters significantly for product engineering and development, less so for applied research, and very little for basic R&D. Interestingly, the location of basic R&D by Japanese electronic and biotechnology corporations is similar to that of large, technology-intensive US and European corporations, where the main location factors are a good living environment, good transportation and availability of engineers. The great majority of basic R&D in Japan is located in the largest cities such as Tokyo and the Osaka–Kyoto area where significant agglomeration economies are present. The findings further suggest that Japanese industry is distinguished by tight organizational and geographic linkages between applied research and production engineering and manufacturing. This is a major difference from the US and much of Europe where these activities are frequently split apart.

Fourth, our field research and interviews with Japanese R&D managers suggest that R&D is increasingly important to corporate strategy in areas such as electronics where Japanese firms are among important global competitors. The findings here indicate that R&D is used strategically by Japanese firms to mobilize existing strengths and leverage established core competencies in order to move into high-growth fields.

In broader conceptual terms, our findings support the hypothesis that different types of knowledge embedded in different corporate functions will require different organizational and geographic mechanisms to transfer effectively. As far as Japanese R&D activity is concerned, different types of knowledge and information are characterized by different levels of physical proximity and organizational linkage. In this case, the tightest linkage is between manufacturing and production engineering. This is the dimension of innovative and production activity which requires the greatest interaction as it evolves. It is also the type of knowledge which is of the most immediate relevance and requires a high degree of incremental improvement to put into practice. Basic R&D tends to be more scientifically based and formal, and thus in its initial stages may require less direct contact with the kind of knowledge associated with manufacturing.

Finally, our research suggests that organizational and geographic dimensions of Japanese R&D tend to reinforce one another. Those functions that are closely linked by organizational factors are also tightly integrated geographically. This in turn suggests that organization and geography may well be mutually reinforcing dimensions of technological and industrial activity.

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