Industrial Innovation in Japan and the United States

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Japanese firms tend to be quicker and more economical than U.S. firms at developing and introducing new products and processes, but this advantage seems to exist only among innovations based on external technology, rather than internal technology. Whereas U.S. firms put more emphasis on marketing start-up, they put much less emphasis on tooling, equipment, and manufacturing facilities than do Japanese firms. Applied R&D in Japan, which focuses more on processes than in the United States, seems to have yielded a handsome return; but there is no evidence that the rate of return from basic research has been relatively high in Japan. In robotics, the Japanese edge seems to increase as one moves from R&D toward the market.

AMERICAN TECHNOLOGICAL LEADERSHIP IS BEING SEVERELY challenged in many high-technology industries by the Japanese (*1*). Yet very little systematic investigation has been carried out to determine how much of an advantage, if any, Japan has over the United States in developing and commercially introducing the new products and processes that are central to success in these industries. Intensive empirical studies have not been conducted to compare the extent, composition, and effectiveness of the research and development (R&D) activities of Japanese firms with those of comparable U.S. firms. We do not have an adequate understanding of the differences between Japan and the United States in the rates of diffusion of many new technologies (*2*).

In this article, I summarize some of the principal results of a 2-year study, based largely on data obtained from carefully selected samples of several hundred Japanese and U.S. firms, which shed new light on these important topics. Differences between the two countries in the quickness and cost of developing and introducing new products and processes are evaluated, and the size, composition, and effects of industrial R&D expenditures in the two countries are compared. Also, the introduction and diffusion in both countries of a particular new technology, the industrial robot, are analyzed.

Table 1. Mean ratio of U.S. to Japanese innovation times and of U.S. to Japanese innovation costs, from data provided by 50 Japanese and 75 U.S. firms for 1985 (*5*).

Industry	Mean ratio of innovation times		Mean ratio of innovation costs	
	U.S. estimates	Japanese estimates	U.S. estimates	Japanese estimates
Chemicals	1.04	0.96	1.02	1.14
Rubber	1.16	1.10	1.16	1.22
Machinery	1.17	1.23	1.21	1.28
Metals	0.99	1.18	0.95	1.10
Electrical	1.03	1.42	1.04	1.32
Instruments	1.00	1.38	1.23	1.40
All industries	1.06	1.18	1.10	1.23

Time and Cost Differentials

In the chemical, rubber, machinery, instruments, metals, and electrical equipment industries (*3*), firms from both countries tend to agree that the Japanese develop and commercially introduce new products and processes more quickly than the Americans, although their advantage in this respect is not as great as is sometimes claimed. This finding is based on detailed data obtained from a random sample of 50 Japanese and 75 U.S. firms. Averaged over all six industries, the time differential in 1985 was about 18%, according to the Japanese firms, or 6%, according to the U.S. firms (Table 1). However, the picture varies from industry to industry. In some industries, like machinery, both the Japanese and U.S. firms indicate that there was a substantial differential. In other industries, like instruments, the Japanese firms indicate that there was a substantial differential, whereas the U.S. firms do not. In still other industries, notably chemicals, both the Japanese and U.S. firms indicate that there was no large differential. These data pertain to the length of time elapsing from the beginning of applied research (if there was any) by the innovator on a new product or process to the date of the new product's or process's first commercial introduction (*4*).

On the average, the Japanese also develop and commercially introduce new products and processes more cheaply than the Americans. Averaged over all six industries, the resource cost differential in 1985 was 23%, according to the Japanese firms, or 10%, according to the U.S. firms. Here too, the situation varies from industry to industry. For example, in machinery and instruments, based on both the Japanese and U.S. estimates, the cost differential seemed substantial; in chemicals, on the other hand, the U.S. firms do not indicate that any substantial differential existed. The cost figures used here include all costs to the innovator of developing and introducing the innovation. Specifically, they include the costs (before the innovation's first commercial introduction) of applied research, preparation of project requirements and basic specifications, prototype or pilot plant, tooling and manufacturing equipment and facilities, manufacturing start-up, and market-

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ing start-up. Because the Japanese cost figures were converted to dollars on the basis of purchasing power parities for resources used in the innovation process, they indicate approximately how much the resources used in Japan would have cost in the United States.

To understand the factors responsible for these cost and time differentials, one must recognize that some innovations are based largely on external technology (that is, technology developed outside the innovating firm), whereas others are based largely on internal technology (that is, technology developed within the innovating firm). To see whether these cost and time differentials depend on whether innovations are based on internal or external technology, I picked a random sample of 60 major Japanese and U.S. firms in the chemical industry (defined broadly to include pharmaceuticals and petroleum), the machinery industry (including computers), and the electrical equipment and instruments industries. The sample is composed of 30 matched pairs; each pair consists of a U.S. and a Japanese firm of roughly comparable size in the same industry. Every firm indicated how much time and money it devoted, on the average, to the development and commercialization of each of the new products it introduced from 1975 to 1985, depending on whether the product was based on external or internal technology. According to expert opinion, the new products introduced by each pair of firms were reasonably comparable.

Like the estimates obtained from the 125-firm sample described above, the results indicate that the Japanese tend to have significant cost and time advantages over U.S. firms. However, these advantages seem to be confined to innovations based on external technology (where the cost and time differentials are greater than those indicated above). Among innovations based on internal technology, there seems to be no significant difference in average cost or time between Japan and the United States (*5*).

Innovations Based on External Technology

As a first step toward understanding why the Japanese have cost and time advantages over U.S. firms with respect to innovations based on external technology, it is important to recognize that, according to the above data, U.S. firms take almost as long, and spend almost as much money, to carry out an innovation based on external technology as one based on internal technology. In the development part of the innovation process (beginning at the start of R&D and ending when the product is developed), a U.S. innovation based on external technology takes less time and money than one based on internal technology; but in the commercialization part (beginning when the product is developed and ending when it is first introduced commercially), the time and cost are at least as great as one based on internal technology.

In Japan, on the other hand, firms take about 25% less time, and spend about 50% less money, to carry out an innovation based on external technology than one based on internal technology. Moreover, this is true in all industries included in my study. The contrast between Japanese and U.S. firms in the commercialization part of the innovation process is particularly striking. Whereas in the United States the commercialization of an innovation based on external technology takes more time and about as much money as the commercialization of one based on internal technology, in Japan it takes about 10% less time and over 50% less money than the commercialization of an internal technology–based innovation.

Many innovations based on external technology are new products that imitate others in important respects. The relatively higher commercialization cost for innovations based on external technology in the United States than in Japan seems to have been due in part to the fact that the Japanese, in carrying out such innovations, have been more likely than the Americans to make significant technical adaptations of the imitated product and to reduce its production costs substantially. The Americans have been more inclined than the Japanese to invest heavily in marketing start-up costs in an effort to position such innovations optimally in the market, the emphasis being more on marketing strategies than on technical performance and production cost. On balance, despite the Japanese emphasis on tooling, equipment, and facilities, this seems to have resulted in relatively high commercialization costs for such innovations in the United States.

Resource Allocation in the Innovation Process

Japanese firms, in carrying out an innovation, allocate their resources quite differently than do U.S. firms. Table 2 shows the proportion of the total cost of developing and introducing a new product (introduced in 1985) that was incurred in each of the following stages of the innovation process: applied research, preparation of project requirements and basic specifications, prototype or pilot plant, tooling and manufacturing equipment and facilities, manufacturing start-up, and marketing start-up. My sample was chosen from the chemical, machinery, electrical equipment, instruments, rubber, and metals industries (*3*). It contains 50 matched pairs, in which each pair consists of a U.S. and Japanese firm of roughly comparable size in the same industry.

The percentage of total innovation cost devoted in Japan to

Table 2. Percentage distribution of innovation costs, 100 firms, Japan and the United States, 1985 (*5*).

Stage of innovation process	Japan* (%)	United States (%)
Applied research	14	18
Preparation of product specifications	7	8
Prototype or pilot plant	16	17
Tooling and manufacturing equipment and facilities	44	23
Manufacturing start-up	10	17
Marketing start-up	8	17
Total	100	100

*Due to rounding, numbers do not sum to total.

Table 3. Company R&D funds as a percentage of net sales, Japan and the United States (*12*).

Industry	Japan (1986)	United States (1985)
Food	0.8	0.4
Textiles	1.2	0.5
Paper	0.7	1.3
Chemicals	3.8	4.7
Petroleum	0.4	0.7
Rubber	2.9	2.2
Ferrous metals	1.9	0.5
Nonferrous metals	1.9	1.4
Fabricated metal products	1.6	1.3
Machinery	2.7	5.8
Electrical equipment	5.1	4.8
Motor vehicles	3.0	3.2
Other transportation equipment	2.6	1.2
Instruments	4.5	9.0
Total manufacturing	2.7	2.8

tooling and manufacturing equipment and facilities is almost double that in the United States. (Moreover, this difference is found in practically every industry in the sample.) This reflects, of course, Japan's emphasis on process engineering and efficient manufacturing facilities. On the other hand, the percentage of total innovation cost devoted to manufacturing start-up is significantly higher in the United States than in Japan. This may reflect greater difficulties in attaining desired quality levels in the United States than in Japan and the tendency of Japanese engineers to work more closely and directly with their work force than American engineers do (*6*).

Particularly striking is the difference in marketing start-up costs—that is, the expenses of pre-introduction marketing activities. In every industry in the sample, the percentage of total innovation cost devoted to marketing start-up in the United States is almost double that in Japan. If U.S. firms could reduce this percentage to the Japanese level (while holding constant the amount they spend on other stages of the innovation process), it appears that about 60% of the Japanese cost advantage would be eliminated (*7*).

Industrial R&D

Many observers are impressed by the efficiency of Japanese industrial R&D. Indeed, the president of the Semiconductor Research Corporation has gone so far as to state that: "The United States may never match Japan's R&D efficiency" (*8*, p. 40). If one is willing to accept a highly simplified, but frequently employed, econometric model (*9*), the results are consistent with the contention that applied R&D in Japan has yielded a higher rate of return (*10*) than in the United States. This contention seems reasonable, given Japan's greater emphasis on commercial (rather than government-financed) projects and its reliance on advanced technology from the West, which could be adapted and improved at relatively low cost. On the other hand, the econometric results provide no indication that basic research has been particularly effective in Japan (*11*). Based on these findings, the Japanese advantage has been confined largely to applied R&D, particularly R&D concerned with the adaptation and improvement of existing technology.

Comparison of official data in both countries shows that the R&D intensity of manufacturing firms has increased more rapidly in Japan than in the United States, which is not surprising, given the previous finding that the rate of return from applied R&D has been higher there than here. In 1986, company-financed R&D expenditures in manufacturing were about 2.7% of sales in Japan, in comparison with about 2.8% in 1985 in the United States (Table 3) (*12*). In 1970, the corresponding figures were 1.3% for Japan and 2.2% for the United States. In all industries other than machinery, instruments, paper, and petroleum, Japan has narrowed the gap substantially. In some industries (food, textiles, metals, and rubber) Japan now leads; in other industries (paper, petroleum, machinery, and instruments) the United States now leads; and in the rest there is a relatively small difference in R&D intensity.

Japanese firms seem to give users of their R&D results a more important role in shaping their R&D programs than do U.S. firms. Japanese firms seem to base about one-third of their R&D projects on suggestions from their production personnel and customers, whereas only about one-sixth of U.S. projects come from these sources. Both production personnel and customers tend to be users of a firm's R&D results. In contrast, U.S. firms seem to put more emphasis than do the Japanese on the R&D function as a generator of R&D projects. Particularly in the electrical equipment industry, U.S. firms tend to base a larger percentage of their R&D projects on suggestions from R&D personnel than do Japanese firms.

Composition of Industrial R&D

Because R&D projects are so heterogeneous, it is important to look behind the total R&D figures at the composition of firms' R&D expenditures. Fifty Japanese firms were chosen at random in the chemical, electrical equipment, instrument, machinery, rubber, and metals industries, and for each Japanese firm I picked at random a U.S. firm of the same industry and approximate size. The firms in this sample carry out about 25% of the R&D in each country in these industries. Based on detailed information obtained from each of these 100 firms (50 matched pairs), the Japanese seem to devote about as large a percentage of their R&D expenditures to relatively risky and long-term projects as do U.S. firms (Table 4). This differs greatly from the early 1970s, when Peck and Tamura characterized Japanese industrial R&D as composed very largely of "low-risk and short-term projects" (*13*).

However, it is by no means true that Japanese and U.S. industrial R&D have become essentially the same. Whereas U.S. firms report that almost one-half of their R&D expenditures are going for projects aimed at entirely new products and processes, Japanese firms report that only about one-third of their R&D expenditures go for this purpose (*14*). (Outside the chemical industry, in which there is little difference in this regard, the gap is even wider.) Of course, this is in accord with a great deal of anecdotal information to the effect that the Japanese devote more of their R&D resources to the improvement and adaptation of existing products and processes (rather than to the development of entirely new products and

Table 4. Composition of R&D expenditures, 100 firms (50 matched pairs), Japan and the United States, 1985 (*9*).

Industry	Percentage of R&D expenditures					
	Basic research	Applied research	Products (rather than processes)	Entirely new products and processes	Projects with <0.5 estimated chance of success	Projects expected to last >5 years
			All industries combined			
Japan	10	27	36	32	26	38
United States	8	23	68	47	28	38
			*Chemicals**			
Japan	11	42	48	42	24	39
United States	11	39	74	43	39	41
			Machinery,† instruments, metals, and rubber			
Japan	9	23	32	28	26	37
United States	4	9	62	51	16	36

*Including drugs. †Including electrical equipment and computers.

Even more striking is the difference between Japanese and U.S. firms in their allocation of R&D resources between projects aimed at improved product technology and projects aimed at improved process technology. The U.S. firms in this sample devote about two-thirds of their R&D expenditures to improved product technology (new products and product changes) and about one-third to improved process technology (new processes and process changes). Among the Japanese firms, on the other hand, the proportions are reversed, two-thirds going for improved process technology and one-third going for improved product technology (*15*).

These results shed new light on a major issue concerning industrial R&D in the United States. Many observers have criticized U.S. industry for neglecting process innovation. As the President's Commission on Industrial Competitiveness puts it, "It does us little good to design state-of-the-art products, if within a short time our foreign competitors can manufacture them more cheaply" (*16*, p. 20). Contrary to the common impression that U.S. firms have in recent years begun to react to such criticism by paying more attention to process innovation than in the past, my results do not indicate that there was any perceptible increase between 1976 and 1985 in the proportion of their R&D expenditures devoted to new or improved processes. Thus, in terms of the allocation of their R&D funds, U.S. firms do not seem to have put more emphasis on processes, despite this criticism.

Industrial Robots: A Case Study

An important industry in which the Japanese are often cited as being ahead of the United States is industrial robots. Given that this is the case, it is interesting to compare the innovation process in the two countries in this industry. From data obtained from a sample of U.S. and Japanese robot producers that account for almost 90% of U.S. robot output and about 20% of Japanese robot output, it appears that the Japanese tend to be faster (by about 20 to 30%) and use less resources (by about 10%) than their U.S. rivals in developing and introducing a new robot (of comparable novelty, importance, and complexity). U.S. firms devote a much larger percentage (37% versus 10%) of innovation cost to marketing start-up, and a much lower percentage (4% versus 23%) to tooling and manufacturing equipment and facilities than do Japanese firms (*17*).

The composition of innovation costs differs between high-growth and low-growth robot producers. In both countries, high-growth robot producers tend to devote a much higher proportion of innovation costs to tooling and manufacturing facilities than do low-growth robot producers, and the proportion devoted to marketing start-up seems to be much lower among high-growth than low-growth robot producers. In this industry at least, it appears that the more successful firms in both countries, like the Japanese, tend to emphasize manufacturing in the innovation process, not marketing.

Given the oft-stated assertion that Japanese managers are often more patient than their U.S. counterparts, it is interesting to note that the proportion of R&D expenditure devoted to relatively long-term projects (those expected to last more than 5 years) does not differ significantly between the two countries—and the sample proportion is higher in the United States than in Japan (Table 5). Moreover, in contrast to other industries (as shown in Table 4), the share of R&D expenditure devoted to new products and product improvements (rather than new processes and process improvements) is higher for Japanese robot firms than for U.S. robot firms. Perhaps this is an indication that, as their technology becomes more advanced and they become world leaders in particular areas, Japanese firms will devote more resources to product R&D (relative to process R&D), and become more like U.S. firms in this respect.

In both countries, high-growth robot producers tend to be more research-intensive and technologically ambitious in their R&D programs than low-growth robot producers. The percentage of sales devoted to R&D was about two or three times as great among high-growth as among low-growth producers. The percentage of R&D expenditures devoted to research (rather than development), and the percentage aimed at entirely new products and processes, was at least twice as high among high-growth as among low-growth producers. In the robot industry, the more successful firms seem to devote a larger share of their R&D to more fundamental and technologically ambitious projects, which is likely to have contributed to their success (*18*).

Table 5. Composition of R&D expenditures, Japanese and U.S. robot producers, 1985 (*18*).

Characteristics of firms*	Percentage of R&D expenditures				
	Basic research	Applied research	New products and product improvements	Entirely new products and processes	Projects expected to last >5 years
Japanese firms	12	23	65	51	10
Large	12	24	65	53	8
Small	11	17	73	10	34
High growth	15	32	73	63	6
Low growth	6	11	51	34	12
U.S. firms	13	21	39	46	17
Large	15	23	41	44	11
Small	2	8	25	56	50
High growth	14	29	48	52	12†
Low growth	15	4	22	19	11†

*In the United States, a small robot producer is one with 1984 sales below $5 million; a large robot producer is one with 1984 sales of $5 million or more. In Japan, a small robot producer is one with 1983 sales below 800 million yen; a large robot producer is one with 1983 sales of 800 million yen or more. In the United States, high-growth producers are defined as those that had more than a 50% average annual increase in robot sales from 1982 to 1985; low-growth producers are those that had a 50% increase or less. (Of course, this is a short period, but the robot industry is very young. In one case where data were unavailable for 1982 to 1985, the growth rate had to be based on only part of the period.) In Japan, high-growth producers are those that had an average annual growth rate of sales of more than 50% during 1979 to 1984; low-growth producers are those that had an average annual growth rate of 50% or less. (In cases where data were unavailable for 1979 to 1984, the growth rates had to be based on only part of the period.) For lack of data, not all of the sample can be classified as "high growth" or "low growth." Joint ventures between U.S. and Japanese firms are omitted, since they are neither purely American nor purely Japanese. †Because of lack of data, not all of the sample can be classified as "high growth" or "low growth." This explains why both these percentages are below the figure of 17% given in this column for all U.S. firms.

The Diffusion of Industrial Robots

Although the industrial robot was largely an American invention, the rate of imitation for industrial robots in the United States was slow, relative to other major industrial innovations. On the basis of data I obtained from a random sample of 100 major firms, it took, on the average, about 12 years (from the date of first use in the relevant industry) for half of the major potential users in ten industries—autos, auto parts, electrical equipment, appliances, steel, nonferrous metals, aerospace, farm machinery, machine tools, and other machinery—to begin using robots (Table 6). In contrast, it took only about 5 years, on the average, for half of the potential users in an industry to begin using numerically controlled machine tools, an important precursor of robots (*19*).

In Japan, where U.S. robotics technology began to be transferred in the 1960s, the rate of imitation was faster than in the United States. On the basis of data I obtained from a random sample of 75 firms, it took, on the average, about 8 years (from the date of first use in the relevant industry) for half of the major potential users in four industries—autos, electrical equipment, metals, and machinery—to begin using robots. In both the United States and Japan, the imitation process can be represented reasonably well by a simple econometric model I suggested a number of years ago (*20*). According to the results, Japan's higher rate of imitation can be explained entirely by its later start, which enabled it to use earlier experience in the United States and elsewhere.

Turning from the rate of imitation (the growth over time in the number of firms using robots) to the intrafirm rate of diffusion (the growth over time in the number of robots used by a firm), it seems clear that the intrafirm rate of diffusion has tended to be much greater in Japan than in the United States. In my sample, the number of robots used per 10,000 employees in 1985 was about four to eight times as great (depending on the industry) in Japan as in the United States (*21*).

In considerable part, this observed difference in robot use between Japan and the United States seems to be due to differences in the minimum rate of return required to justify investing in robots. Whereas the Japanese often invest in robots yielding returns of 20%, U.S. firms frequently insist on 30% or more. This difference in minimum required rates of return has been noted in other studies as well, and it may reflect a tendency, cited by Kaplan (*22*) and others, for U.S. firms to exaggerate their cost of capital. On the basis of data I obtained from the Japanese firms in the sample, it seems that, if they had applied the same "hurdle rates" as their U.S. rivals, their robot use would have fallen by 50% or more.

Table 6. Number of years before half of major potential users introduced robots, Japan and United States, by industry (*19*).

Industry	Number of years
United States	
Autos and trucks	15
Auto parts and equipment	8
Electrical equipment	17
Appliances	19
Nonferrous metals	20
Steel	3
Farm and construction machinery	18
Machine tools and industrial machinery	16
Other machinery*	1
Aerospace	7
Mean	12
Japan	
Autos	6
Electrical equipment	2
Metals	9
Machinery	15
Mean	8

*Because the sample in this industry is small, this result should be treated with considerable caution.

Conclusions

At least five conclusions seem to follow from the studies described above. First, with respect to the differences between the two countries in innovation cost and time, the situation is much more varied and complex than is generally portrayed by the largely anecdotal accounts that have begun to appear. Whereas the Japanese have substantial advantages in this regard in some industries (notably machinery), they do not seem to have any substantial advantage in others (notably chemicals). Whereas they have very great advantages in carrying out innovations based on external technology, they do not seem to have any in carrying out innovations based on internal technology.

Second, a large part of America's problem in this regard seems to be due to its apparent inability to match the Japanese as quick and effective users of external technology. As Brooks has warned, "The United States, so long accustomed to leading the world, may have lost the art of creative imitation" (*23*, p. 17). This is not to deny that part of the Japanese advantage may be due to factors like their propensity to overlap various stages of the innovation process, their subcontractor network, and their fewer organizational barriers and better communication between functional departments of firms. But the fact that the Japanese advantage tends to be limited to innovations based on external technology suggests that it is in this area that many central problems lie.

Third, part of these problems may be related to the differences between Japan and the United States in the way resources are allocated in the industrial innovation process. Whereas U.S. firms emphasize marketing start-up to a much greater degree than do the Japanese, they put much less emphasis on tooling, equipment, and manufacturing facilities than do Japanese firms. Perhaps U.S. firms might consider whether they safely can reduce the cost and time devoted to marketing start-up without impairing the vital interface between R&D and marketing. Although it would be foolish for the United States, which has long been at the forefront of industrial innovation to attempt mindlessly to mimic the Japanese, it would also be foolish not to try to learn from them.

Fourth, my results, which are subject to many limitations detailed elsewhere (*9*), support the contention that applied R&D in Japan has yielded a handsome return, higher than in the United States. In large part, this can be explained by Japan's greater emphasis on commercial (rather than government-financed) projects, by its ability to obtain Western technology that was more advanced than its own, and which could be adapted and improved at relatively low cost, and by its emphasis on process technology, which according to many experts has tended to be neglected in the United States. On the other hand, there is no evidence that the rate of return from basic research has been relatively high in Japan. Apparently, the Japanese advantage has been confined largely to applied R&D, particularly R&D concerned with the adaptation and improvement of existing technology.

Fifth, my results concerning robotics, an important area where the Japanese currently seem to have an edge, suggest that the Japanese advantage increases as one moves from R&D toward the market. Whereas the Japanese seem to be quicker and more efficient innovators, they do not seem to be more effective at R&D. Whereas they have introduced many more robots than U.S. firms, they have

not been quicker to begin using them (when account is taken of their later start). If, as many observers claim, U.S. industry has not used robots as fully as it should, the principal fault does not seem to lie with U.S. R&D. Instead, this case seems to illustrate the contention that, in those areas where the United States is falling behind competitively, it is due frequently to problems not so much in R&D or inventiveness, but in the commercial application of science and technology.

REFERENCES AND NOTES

1. For important studies of the relation between technological change and economic growth, see E. Denison [*Trends in American Economic Growth* (Brookings Institution, Washington, DC, 1985)] and J. Kendrick [J. Kendrick, Ed., *International Comparisons of Productivity and Causes of the Slowdown* (American Enterprise Institute/Ballinger, Washingon, DC, 1984)].
2. For two articles dealing with the competitiveness of U.S. industry, see S. Cohen and J. Zysman [*Science* **239**, 1110 (1988)] and L. C. Thurow [*ibid.* **238**, 1659 (1987)].
3. The chemical industry referred to in this section includes pharmaceuticals; the machinery industry includes computers.
4. The overall U.S.–Japanese differences in Table 1 are highly significant in a statistical sense; the all-industry mean ratios differ from 1.00 at the 0.01 probability level. This is also true for many of the figures in the machinery, instruments, and chemical industries, but in other industries like metals and rubber, many of the figures are based on relatively few observations. Note too that, although the estimates in Table 1 were based on reasonably precise data concerning the firms' own times and costs, they sometimes had to be based on the best judgment of the firms' leading executives concerning their rivals' times and costs. The data in my 60-firm sample described later in this article are free of this problem.
5. For a more detailed account of the studies in this and the next two sections, see E. Mansfield (*Manage. Sci.*, in press).
6. It may also be related to the fact that the percentage of innovation cost devoted to tooling and manufacturing equipment and facilities is lower in the United States than in Japan.
7. For all industries combined, the difference between Japanese and U.S. firms in the percentage of innovation cost devoted to tooling and manufacturing cost and facilities, as well as the difference between them in the percentage devoted to marketing start-up costs, is statistically significant at the 0.01 probability level.
8. L. W. Sumney and R. M. Burger, *Issues Sci. Technol.* **3**, 32 (summer 1987).
9. For this model as well as a more detailed account of the studies described in this and the next section, see E. Mansfield [*Am. Econ. Rev.* **78**, 223 (1988)].
10. As pointed out in (*9*), this rate of return pertains to entire industries, not to particular firms, in Japan and the United States.
11. The National Science Foundation's definitions of basic research, applied research, and development are used here.
12. Bureau of Statistics, *Report of the Survey of Research and Development in Japan* (Bureau of Statistics, Tokyo, 1987); National Science Foundation, *National Patterns of Science and Technology Resources, 1987* (Government Printing Office, Washington, DC, 1988). G. Saxonhouse translated the Japanese material.
13. M. J. Peck and S. Tamura, in *Asia's New Giant*, H. Patrick and H. Rosovsky, Eds. (Brookings Institution, Washington, DC, 1976).
14. Of course, the distinction between an entirely new product or process and an improved or modified product or process is often arbitrary (although it frequently is used).
15. Among the large R&D spenders (top 20%), this difference between U.S. and Japanese firms is significant at the 0.01 probability level. From the point of view of the economy as a whole, a large proportion of the resources allocated to product technology in the United States really goes for processes, since one firm's products frequently are parts of another firm's processes. Thus, this difference between Japan and the United States reflects a difference in how much of the process R&D for a given product is carried out by the producers of the product and how much is done by equipment producers and other suppliers of the producers of the product. As many observers have stressed, there can be disadvantages in leaving this sort of R&D to the latter firms. (Of course, the observed U.S.-Japan difference in this regard is due partly to differences in industrial and firm structure.)
16. President's Commission on Industrial Competitiveness, *Global Competition: The New Reality* (Government Printing Office, Washington, DC, 1985).
17. These U.S.–Japanese differences are statistically significant. For a more detailed account, see E. Mansfield (paper presented at Symposium on Research and Development, Industrial Change and Economic Policy, University of Karlstad, Sweden, June 1987). Also, see R. Ayres, L. Lynn, and S. Miller [in C. Uyehara, Ed., *Technological Exchange: The U.S.–Japanese Experience* (University Press of America, Washington, DC, 1982), pp. 77–115].
18. E. Mansfield, *Manage. Decis. Econ.*, in press. For the statistical significance of these differences, see E. Mansfield in (*17*).
19. ———, "The diffusion of industrial robots in Japan and the United States" (working paper, Center for Economics and Technology, University of Pennsylvania, Philadelphia, 1987).
20. ———, *Econometrica* **29**, 741 (1961).
21. Also see K. Flamm [*International Differences in Industrial Robot Use* (Brookings Institution and Development Research Department, World Bank, Washington, DC, May 1986)].
22. R. Kaplan, *Harv. Bus. Rev.* **64**, 87 (1986). According to some economists, the cost of capital is higher in the United States than in Japan. This too might account for the higher hurdle rates in the United States than in Japan.
23. H. Brooks, *Japanese Technological Advances and Possible United States Responses Using Research Joint Ventures*. Testimony before Subcommittee on Science, Research and Technology of the House Committee on Science, Space, and Technology, 98th Cong., 1st sess., 29 to 30 June 1983.

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