U.S. Leadership in Technology

If the United States can maintain a competitive advantage, it is likely to be built on technology.[34] The reason is simply ‘hat ‘he United States has substantial competitive disadvantages relative to most other nations in some areas – for example, wage rates and capital costs. U.S. wages are among the highest in the world, and during the first half of the 1980s probably were the highest. The falling dollar has lowered American wages vis-a-vis those of a few other developed nations – in particular, West Germany and Japan – but, in general, American wages are still high compared with those of most of our trading partners. As for capital costs, U.S. interest rates were substantially higher in the 1980s than those in much of the rest of the world.

Technology has been a traditional source of U.S. strength, compensating for these disadvantages. Our technological advantage in the past rested on the invention of new products (e.g., Nylon, photocopy machines, integrated circuits), ‘swift adoption and efficient manufacture of products invented elsewhere (e.g., electric generators, stainless steel, jet engines), and improvements in the manufacturing process. The last includes not only designing and using better equipment but also organizing work and managing people so as to make efficient use of the equipment.

The commonly used measures of technological advantage or progress are not very satisfactory. Most are indirect; for example, many are measures of inputs, such as spending on research and development, or they are rough proxies for outputs of R&D, such as patent grants. In general, they do not tell us much about how well technology is being used in the production of goods. It is impressive, however, that most of the conventional technology indicators point in the same direction, and so do case studies that measure more directly the practical use of technology in manufacturing. In relation to other countries and to our own history, the United States is losing ground.

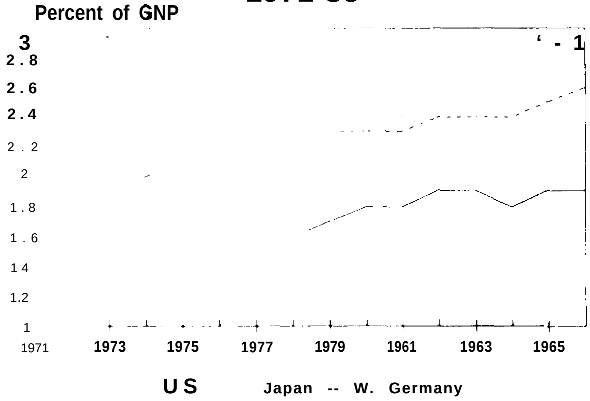
The dominating technological lead the United States enjoyed in the 1950s and 1960s was bound to narrow or disappear in many fields, since our advantage was in part the result of wartime destruction of European and Japanese industry. There are indications, however, that America’s relative decline is not just the natural effect of growth in other countries but also reveals a fundamental weakening in our ability to use technology to make things cheaply and well.

Japan and Germany are ahead of the United States in the kind of R&D spending most likely to pay off commercially. Spending by American companies and government agencies for non-defense R&D rose quite steadily (in constant dollars) in the 1970s and 1980s, and in absolute terms the United States leads the world. But that lead simply reflects the size of the U.S. economy. In civilian R&D as a percentage of gross

34 In a few industries, competitive advantage may also be built on unique endowments of natural resources. For example, the American paper and lumber industries have substantial advantages over most other nations because of their access to a large, high quality softwood resource.

domestic product, we are trailing Japan and Germany by increasing margins (figure 14).[35] Our civilian R&D spending was 1.9 percent of GDP in 1985, compared to 2.8

**Figure 14.
Non-Defense Research and Development, Percent GNP
1971-86**



NOTE: Latest data for West Germany are NSF estimates based on preliminary national data.

SOURCE: National Science Foundation, International Science and Technology Update 1987 (NSF 87-319) (Washington, DC: 1987). p.7.

percent in Japan and 2.5 percent in Germany. If defense R&D is included, total U.S. spending for R&D is about equal to Japan's and Germany's, as a percentage of GNP. However, the commercial payoff from defense R&D is uncertain; although it has sometimes been seminal for commercial applications, such spinoffs tend to be long-range and indirect.

Japan has spurted still farther ahead in private business spending for R&D. In the early 1970s, the United States, Germany, and Japan were about on a par in business-funded R&D, as a percentage of gross domestic product (table 2). Today, Japanese companies are far ahead of their American counterparts, an indication of the seriousness of their commitment to technological eminence. German companies are also raising their rates of R&D spending faster than U.S. businesses, though not at the pace of the Japanese. Money spent on research and development is of course an imperfect measure of effective efforts toward technological progress; the money spent may or may not pay off in the marketplace. Even so, the fact that the Japanese and German leads are widening is reason for concern about America's future technological prowess.

In human resources devoted to R&D–another input measure — the United States is ahead, but the gap with other countries, especially Japan, is narrowing. In 1984, the

Table 2.-Business-Funded R&D As a Percentage of Gross Domestic Product

	1972	1981	1983	1985	1986
United States	0.99%	1.22%	1 32%	1.3%	1.42%*
Japan .,	1.15	1.73	1.99	2.09	2 14*
Federal Republic of Germany	1.08	146	1.56	1.64	1 69*

• Estlmatad

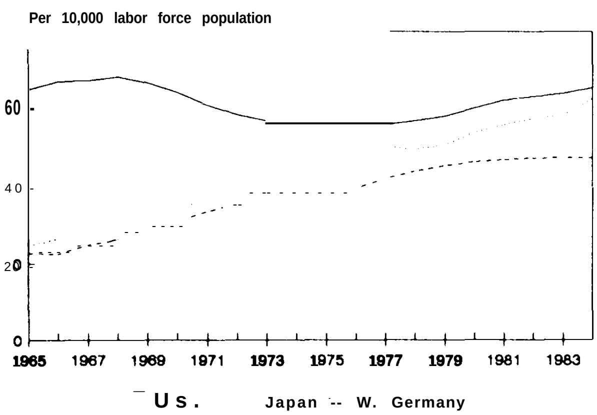
SOURCE: U S Congress, Office of Technology Assessment, International Competition Services, OTA-ITE-328 (Washington, DC: U S Government Printing Office, July 1987), p 19

35 Some analysts argue that the total amount of R&D spending in a nation is more significant than the amount of spending relative to GNP. However, spending as a share of GDP takes into account the size of the nation's economy and indicates how R&D ranks in importance in the nation's total expenditures.

36 U.S. Congress, Office of Technology Assessment, "R&D in the United States and in Other OECD Countries," staff paper prepared for the Subcommittee on Economic Stabilization, House Committee on Banking, Finance and Urban Affairs, November 1983.

number of scientists and engineers engaged in R&D, as a percent of the labor force, was still higher in the United States than in other market-oriented countries (figure 15), but Japan had almost closed on the U.S. levels.[37] (There is no international information on the proportion of researchers working in the civilian versus the defense sector, but the Japanese defense sector is relatively small; most resources devoted to R&D are on the civilian side.)

Figure 15. Scientists and Engineers in Research and Development, Per 10,000 Labor Force Population



SOURCE: National Science Board, Science and Engineering indicators -1987, (Washington, DC: National Science Foundation, 1987) p. 227, Appendix table 3-17

Other measures also document the Japanese challenge. For example, in 1983, Japanese universities graduated 69,600 bachelor-level engineers, while only slightly more – 73,000 engineers – received bachelor degrees in the United States. Japan's labor force is barely more than half the size of ours.[38] University education of engineers in Japan may not be the equal of that in the United States; most Japanese engineers extensive additional training on the job.[39] Nevertheless, Japanese industry has nearly twice the engineering graduates, per capita, to choose from and train if necessary. Moreover, in the United States, defense industries siphon off about 20 percent of the Nation's engineers. Engineering talent, as opposed to scientific, is indispensable for applying research to the development of new products and manufacturing processes.

In terms of our own past history, the number of engineers and scientists graduating from American universities is rising; in particular, more engineers than ever are receiving bachelor's degrees (figure 16). Doctoral degrees in engineering dropped off sharply, however, in the 1970s and despite a recovery had not regained the 1972 peak by 1985 (figure 17). The recovery depended almost entirely on an infusion of foreign students. In 1985, 57 percent of engineers getting doctoral degrees were foreigners.[40]
these foreign engineers remain in the United States, at least for a time, contributing especially to university faculties and to nondefense technology, since most defense work is done by U.S. citizens. But eventually a substantial number return home. Many American engineers see no need for a doctoral degree, since they can get a good job with a bachelor's or master's degree. But the sharp dropoff in doctoral degrees awarded to

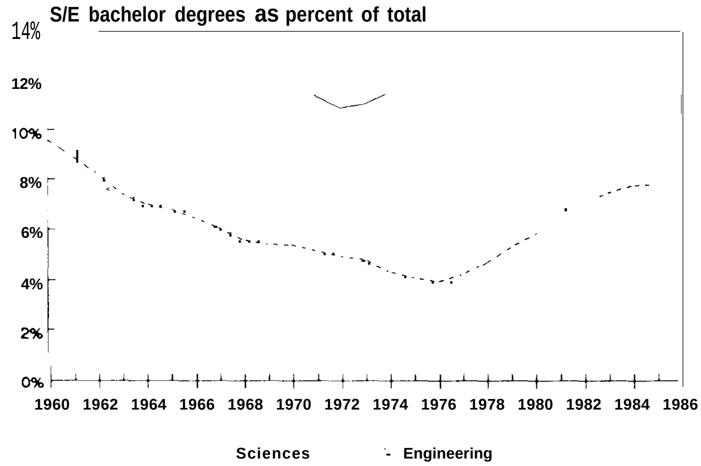
37 The Soviet Union claims a higher share of scientists and engineers in the labor force than any other major country. The Soviet Union's uneven record in technological performance (e.g., high in space exploration, low in production of consumer goods) reflects factors other than human resources devoted to science and technology.

38 National Science Foundation, International Science and Technology Data Update 1986, NSF-307, p.28. In 1982, more engineers received bachelor level degrees in Japan than in the United States (74,000 vs. 67,000).

39 See U.S. Congress, Office of Technology Assessment, International Competitiveness in Electronics, OTA-ISC-200 (Washington, DC: U.S. Government Printing Office, November 1983), pp. 314-17.

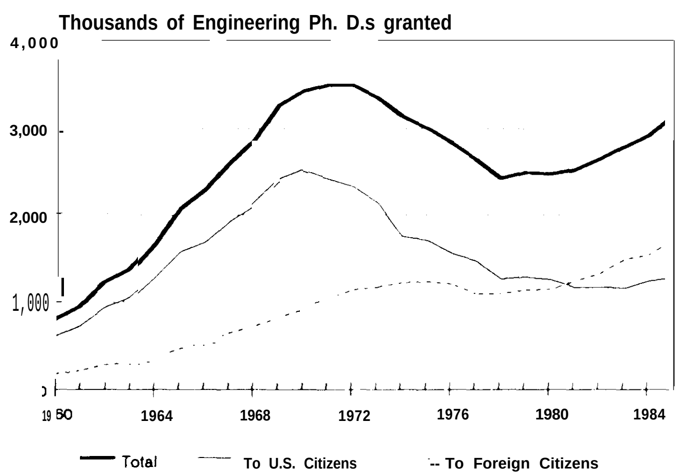
40 National Science Foundation, Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook NSF 86-305 Revised (Washington, DC, 1987).

Figure 16.
U. S. Science and Engineering Bachelor Degrees Granted, Percent of Total Degrees Granted



SOURCE: Office of Technology Assessment contractor report, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-85," Betty M. Vetter (Commission on Professionals in Science and Technology) and Henry Hertzfeld (Consultant), NTIS order #PB 88-177 928/AS.

Figure 17.
U.S. Engineering Ph.D.s Granted to U.S. Citizens and Foreign Citizens, 1960-86



NOTE: The totals do not equal U.S. recipients plus foreign recipients because the citizenship of some students is not known.

SOURCE: National Science Foundation, Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook @Washington, D. C.: National Science Foundation, 1986), table B-21.

U.S. citizens may signal a serious problem in finding well-qualified engineers for research and teaching in universities — the seedbed for future engineering progress.

In other ways as well, Americans are lagging in the human skills needed to use technology to improve manufacturing. Our public schools are turning out graduates who do not measure up internationally. This is especially true in mathematics; for example, in an algebra test given to thousands of 12th grade students in 1982, American students came in 14th, just ahead of Thailand and behind Hungary. Hong Kong ranked first, slightly ahead of Japan. Maintenance and repair jobs, which are vitally important to computerized automation in manufacturing, require technicians with mathematical abilities. People who operate the computerized equipment need certain basic skills. They have to be able to read instructions, grasp the concept of statistical quality control, communicate with fellow workers, and understand their own part in a complex manufacturing process. However, it is not easy to measure how the lack of these skill; exerts a dragon American manufacturing. A strong argument can be made that failure of managerial skills has also been a serious handicap in the past 10 or 15 years, as one U.S. industry after another has lost competitive position. It is axiomatic, though, that a well-trained, well-educated work force is a positive force in maintaining technological advantage.

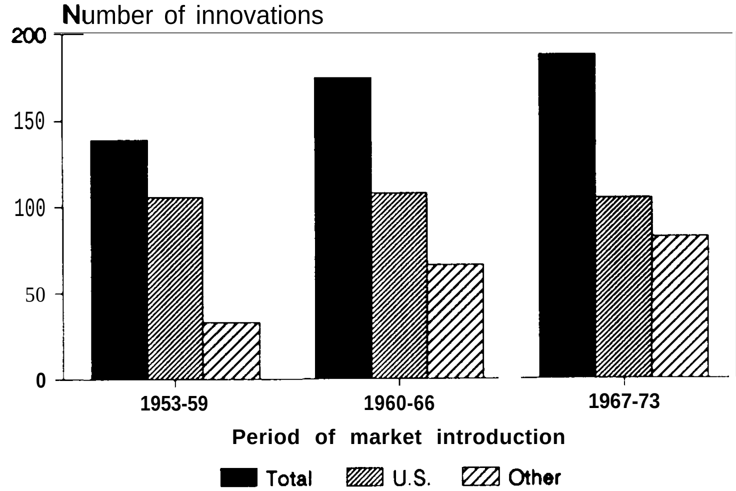
One way of evaluating the results of a nation's R&D efforts is to count up, in some fashion, the innovations it contributes. A well-known attempt at a cross-country comparison of innovativeness was the study sponsored by the National Science Foundation in the mid-1970s. Experts from six countries (the United States, Great Britain, West Germany, France, Japan, and Canada) selected and examined 500 technological innovations that were introduced into the international marketplace from 1953 to 1973.[42] Included on the list were such things as lasers, disc brakes for autos, fiber optics, a new antibiotic, and a camera with self-developing color film. The great majority of the innovations the group considered occurred in the United States (319 of the 500), but the share of U.S. innovations showed a declining trend over the 21 years (figure 18). No new international study of this kind has been done.

Another conventional indicator of R&D results is patent applications or grants. These data support the story of former American dominance and current decline, with the Japanese as principal challengers. U.S. patent data are especially telling. Patents granted to U.S. inventors peaked in 1971 (figure 19). By 1985, patents of foreign origin accounted for 46 percent of the total granted in the United States, with Japan — once again the leader among foreign nations – representing 19 percent. This record is all the more impressive in light of the fact that foreigners tend to patent only their more proven and useful developments in the United States, since it is expensive and inconvenient to apply for patents in countries other than one's own.

41 There is, however, a strong correlation between higher income and higher education, and low levels of education are strongly correlated with high unemployment rates. See: U.S. Congress, Office of Technology Assessment, Technology and the American Economic Transition, OTA-TET-283 (Washington, DC: U.S.GPO, 1988)

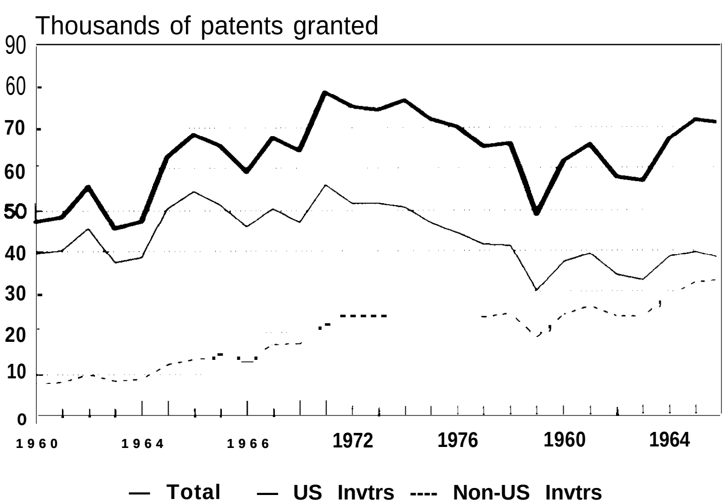
42 Gellman Research Associates, Inc., Indicators of International Trends in Technological Innovation, report prepared for the National Science Foundation under contract no. NSF-(X89, April 1976.

Figure 18.
Trends in Technological Innovation



SOURCE: Research Associates Inc., Indicators of International Trends in Technological Innovation, report prepared for the National Science Foundation, 1976, table 3-1.

Figure 19.
U.S. Patent Grants by Nationality of Inventor 1960-86

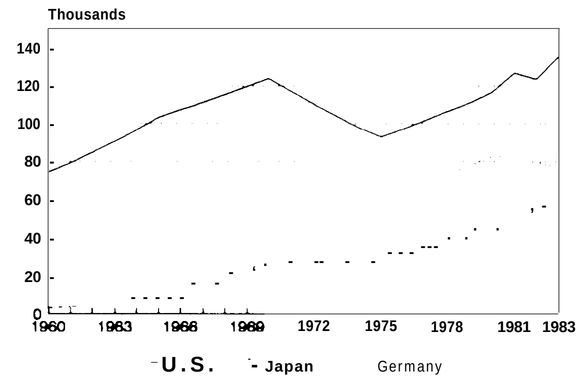


SOURCES: National Science Board, science Indicators -1965, (Washington, DC: National Science Foundation, 1986) p. 256; U..S. Department of Commerce, United States Patent Office, Office of Technology Assessment and Forecast, Technology Assessment and Forecast Report, (Washington, DC:U.S. Government Printing Office, 1973).

Not only has the domestic share of U.S. patents declined; patents to U.S. nationals have fallen sharply in absolute numbers since 1971. In a recent assessment, OTA considered possible reasons for this decline, considering that R&D spending has risen steadily .43 Was the R&D process ineffective in getting results, or had U.S. firms decided deliberately not to seek patent protection? The analysis found evidence that the first possibility is more likely. In a recent survey, 100 U.S. firms reported that they sought to patent a greater percentage of developments in the period 1980-82 than in 1965-69.[44] If the propensity to patent is greater, and spending is higher, then it appears that spending has become less effective. Moreover, the National Science Foundation reports that, in thousands of influential journals throughout the world, research publications by American authors in the fields of engineering and technology fell steadily from 42 percent of the total in 1973 to 38 percent in 1982.[45]

Patenting in OECD countries by residents of other countries shows a brighter picture for the United States (figure 20). External patenting, as mentioned above, is a good indicator of the value companies place on their new technical developments since the expense and bother of applying in a foreign country tends to weed out trivial innovations. In OECD countries, U.S. nationals are the undisputed leaders in external patenting; they even had something of a surge in 1983 while Japanese applications dropped slightly. The Germans, despite recent declines, are still a strong second. Whether the U.S. surge in 1983 represented a one-time backlog or a real trend can only be proven when data for later years become available. The Japanese record remains impressive. Starting with about 3,000 applications in 1960, the Japanese advanced to more than 55,000 in 1983.

Figure 20. External Patent Application By Nationality of Applicant



SOURCE: Organization for Economic Cooperation and Development, Science and Technology Indicators II: R&D, Inventiveness and Competitiveness (Paris: OECD, 1986), tables 24 and 26.

The main failing of patents as a measure of technological advance is that most patents are not commercialized; even external patents may or may not lead to commercial development. Productivity, another commonly used indicator, does not have this defect, since technology must be put to use in industry before it can contribute to a rise in productivity. Although productivity is but one factor in competitiveness, it is an important one. The U.S. record in improving manufacturing productivity is, all-in-all, not a bad one compared to Europe, especially in recent years; in the 1980s, our productivity

43 U.S. Congress, Office of Technology Assessment (1987), op. cit., p. 200.

u Id., citing E. Mansfield, "Studies of Tax Policy, Innovation, and Patents: A Final Report," report to the National Science Foundation, October 198S, p. 6.

45 National Science Foundation, op. cit., p. 38.

growth rates have been as good or better than those of most of the big European countries. But Japan continues to beat all the advanced countries in productivity growth. That story is told below.

The core question, however, is whether American manufacturers are falling behind in the practical application of technology–using it to produce high quality goods at affordable cost. There are no aggregate data that really answer this question. The best way to approach it is to analyze firms and industries, case by case, to see how much and how well technology is contributing to U.S. competitiveness. OTA is doing that for the full assessment of Technology, Innovation, and U.S. Trade, of which this report is an interim product. A number of such case studies have already been done, by OTA and others. It is fair to say from the work already completed that the reputation of U.S.-made goods for quality and reliability has suffered in recent years and that American manufacturing methods are no longer the paradigm for the world.

One of the best examples of such work is Jaikumar's study of flexible manufacturing systems (FMS) in the United States and Japan.[%] A flexible manufacturing system is a production unit which is designed to manufacture different kinds of parts (for example, transmission cases or clutch housings for trucks and farm machinery) in relatively small batches. The FMS is made up of semi-independent work stations (such as numerically controlled machining centers), connected by automated material handling systems (conveyor belts, robots) and controlled by computer. Jaikumar compared how Japanese and American firms used FMSs, and concluded that American firms had used the technology far less effectively than the Japanese. The American systems produced many fewer kinds of parts, took longer to develop, and performed less reliably. For example, U.S. firms typically took 2.5 to 3 years to develop FMSs, compared with 1.25 to 1.75 years in Japan; produced only 10 different kinds of parts compared with the Japanese average of 93; and produced an average of 88 units per day compared with 120 in Japan. In Jaikumar's words, "[r]ather than narrowing the competitive gap with Japan, the technology of automation is widening it further."[47]

Jaikumar attributed the relatively poor performance of FMS in the United States to management, not to differences in machine quality or performance, or in the complexity or size of parts produced. American managers tended to prevent workers from making changes to the system once it was operating, treating the flexible automated technology in much the same way that dedicated, hard-wired automated equipment is used for mass production, and losing both efficiency and flexibility in the process. "If it ain't broke, don't fix it," was the attitude common among American managers.[48] Having spent much more time than the Japanese getting their FMSs up and running, American managers tried to nail down a standard operating procedure and stick to it. Japanese managers, on the other hand, were willing to continue tinkering and changing and improving their FMS installations. This constant emphasis on incremental redesign and improvement is in fact widely cited as a

46 Ramchandran Jaikumar, "Postindustrial Manufacturing," Harvard Business Review, Nov-Dee, 1986
47 Ibid., p. 69.
48 Ibid., p. 71.

strength throughout Japanese industry, and a major factor behind the rapid improvement c)) Japanese productivity in manufacturing.

Japanese firms emphasize process technology more than American firms. In a study of industrial innovation in 50 Japanese and 75 American firms, Mansfield found that the U.S. firms devoted about two-thirds of their R&D resources to improvement in product technology and one-third to improved process technology. The proportions were reversed for the Japanese firms. Mansfield also found that Japanese firms spend twice as much as their U.S. counterparts on tooling and manufacturing equipment and facilities for new products, and half as much on manufacturing and marketing start-up.

While the Japanese have taken pains to master process technology, they have not neglected product development. Many new Japanese products were indeed based on American or European innovations, but the incremental adaptations made by Japanese firms often culminated in a product essentially different from the original innovation. The development of the videocassette recorder has become a classic example of how continual incremental refinement of someone else's basic invention, combined with heavy emphasis on manufacturing process development, enabled Japanese firms to come up with a product that was wholly new.[51] Moreover, the Japanese emphasis on excellence in process technology has shown up in a stream of production-related innovations that American producers in a variety of industries are eager to adopt, such as design for manufacturability, just-in-time inventory control, and statistical quality control. It should be noted that many of the Japanese strengths in production organization were first formulated by American efficiency experts like W. Edwards Deming and J.M. Juran, although it was in Japanese, not American, factories that they were applied with the most diligence.

One of the factors that helps explain the relatively poor American showing in manufacturing performance and technology is the link between production and research/development/design. Constant flows of people, information, and ideas between research and production is characteristic of Japanese firms.[52] In American firms, the processes of research (or design) and production are more often sequential, with the results of developmental work handed over to a different set of people for management of production. There is much less interaction between the designers of the product and the production managers. Japanese auto companies, for example, require just 43 months to take a model from the initial concept to full production; U.S. auto companies require 63 months to do the same.[53] What accounts for this 20-month lead, which can be crucial in adapting to market trends? Not

49 See, for example, Christopher Freeman, Technology Policy and Economic Performance: Lessons from Japan, University of Sussex, Science Policy Research Unit (London: Pinter Publishers, 1987), and A. Altshuler, M. Anderson, D. Jones, D. Roos, and J. Womack, The Future of the Automobile: The Report of MIT's International Automobile Program (Cambridge, MA: MIT Press, 198S).

50 Edwin Mansfield, "The Speed and Cost of Industrial Innovation in Japan and the United States: External vs. Internal Technology," mimeo, n.d.

51 See, for example, James Lardner, Fast Forward: Hollywood, the Japanese, and the VCR Warn, (New York: W. W. Norton & Company, 1987), and M.B.W. Graham, RCA and the VideoDisc: The Business of lesearch (Cambridge.: Cambridge University Press, 1986).

52 See, for example, U.S. Congress, Office of Technology Assessment, Strategies for Commercialization of High-Temperature Superconductivity, (Washington, DC: U.S. Government Printing Office, forthcoming); and Altshuler, et. al, op. cit.

53 Kim B. Clark and Takahiro Fujimoto, "Overlapping Problem Solving in Product Development," Harvard Business School Working Paper 87-048, March 1987.

from spending more: Japanese automakers use only about half as many engineering hours to complete a comparable project ("clean sheet" design of a new automobile and its production) as American automakers.[54] Clark and his colleagues concluded that the Japanese automakers' design processes are more efficient because they give a single "heavy manager" authority over the whole project; the people doing research, development and design are in constant communication with the people responsible for manufacture; conflicts are aired and settled early; product and process design are treated as simultaneous rather than sequential activities.

There are other Japanese strengths. Among those most often cited are greater attention to product quality and reliability, consensus building, and emphasis on long-term market share rather than short term profit. All are difficult to quantify, but firsthand observations, case studies, and the remarkable record of Japanese industrialization and adaptation in the postwar period support the basic point: Japanese manufacturers have moved into a commanding position in many industries and have surpassed U.S. rivals in many important markets by developing and applying technology.[55]

While the record of technology development and application is mixed in different European countries and industries, there are also European examples of aggressive use of new technology to create a competitive advantage. One of the best known is textile industry machinery. Nearly all new weaving machines in American textile mills come from Europe (West Germany and Switzerland) or Japan. Unlike American suppliers, European manufacturers have introduced a new generation of equipment every couple of years. The new equipment is often programmable, can weave a variety of widths, and is faster and quieter than the best American weaving machines. Little wonder, then, that import penetration in textile machinery has increased from 7 percent of the U.S. market in 1960 to nearly 58 percent in 1986. Import penetration in weaving machinery was nearly 85 percent.[56]

The improvement in Japanese and other foreign producers' manufacturing efficiency, quality and performance has elicited a number of responses from American firms. Some responses have been helpful, and others have not. Overall, however, the responses made by U.S. manufacturers have not stabilized or improved America's position in world manufacturing.

54 Kim B. Clark, W. Bruce Chew, and Takahiro Fujimoto, "Product Development in the World Auto Industry: Strategy, Organization and Performance," paper presented to the Brookings Institution Macroeconomics Conference, December 3,1987.

55 We should not attribute too much of the Japanese record to this one set of factors, however. The Japanese home market is and has been much less pervious to imports, particularly in sectors targeted for development, than the American market, despite such widely-cited examples of growing American protectionism as the Multifiber Arrangement and Voluntary Restraint Agreements on Japanese auto imports. This subject – how foreign governments use trade and industrial policies to promote industrial development and manage competition from American and other developed-country products – is taken up in the full assessment, Technology, Innovation and U.S. Trade.

56 U.S. International Trade Commission, U.S. Global Competitiveness: The U.S. Textile Mill Industry, Report to the Committee on Finance, U.S. Senate, USITC Publication 2048, December 1987.