Japan's Growing Technological Capability

Implications for the U.S. Economy

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Since 1985 the National Academy of Sciences and the National Academy of Engineering have engaged in a series of high-level discussions on advanced technology and the international environment with a counterpart group of Japanese scientists, engineers, and industrialists. One outcome of these discussions was a deepened understanding of the importance of promoting a more balanced two-way flow of people and information between the research and development systems in the two countries. Another result was a broader recognition of the need to address the science and technology policy issues increasingly central to a changing U.S.-Japan relationship. In 1987 the National Research Council, the operating arm of both the National Academy of Sciences and the National Academy of Engineering, authorized first-year funding for a new Office of Japan Affairs (OJA). This newest program element of the Office of International Affairs was formally established in the spring of 1988.

The primary objectives of OJA are to provide a resource to the Academy complex and the broader U.S. science and engineering communities for information on Japanese science and technology, to promote better working relationships between the technical communities in the two countries by developing a process of deepened dialogue on issues of mutual concern, and to address policy issues surrounding a changing U.S.-Japan science and technology relationship.

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Preface

Less than 50 years since the end of World War II, Japan has transformed itself from a defeated nation with a devastated economy to an economic superpower. The reasons for the rise of Japan to economic superpower status are multifaceted, but one of the most striking reasons has been the growing prowess of Japanese firms in high technology industries. As little as two decades ago, Japanese firms were generally considered to be marginal players in these industries. Today, by contrast, Japanese firms are now the acknowledged technological leaders in many advanced sectors. Even in other high technology sectors where the high ground is still held by U.S. firms, Japanese firms are often the prime challengers. The high technology prowess of Japanese firms is indeed a main reason why Japan is considered an economic superpower today.

The growing Japanese role in high technology raises a number of questions for the United States. Some of these questions relate to the current status of the two countries, for example, in what industries do Japanese firms hold technologies more advanced than their U.S. rivals? Are there industries in which U.S. firms still lead but are under serious challenge by Japanese firms? Are there sectors in which a U.S. lead is widening?

More fundamental questions can be asked as well. Why has the relative position of U.S. and Japanese firms in so many industries changed so drastically in such a short period of time? Is this trend likely to continue and, if so, why? How do Japan's growing capabilities in a wide range of high technology industries affect the relative competitiveness of the Japanese and U.S. economies? What other implications (other than those affecting competitiveness) does Japan's growing technological capability hold for the U.S. economy?

More specifically, is the research and development function within Japanese firms organized in such a way as to enable these firms to commercialize new technologies more effectively than their U.S. rivals? What are the implications of Japanese direct investment in the high technology sectors in the United States and the consequent control of U.S. R&D activities by Japanese firms? What should be the U.S. policy response to the Japanese challenge in this area?

In 1991, the Committee on Japan of the National Research Council organized a symposium to address these and related issues. The papers included in this volume were first presented at that symposium entitled "Japan's Growing Technological Capability: Implications for the U.S. Economy" held at the National Academy of Sciences on October 23–24, 1991, and were revised later by the authors. The overview chapter was prepared after the symposium. This volume and the symposium are both parts of an ongoing effort by the Committee on Japan to explore new ways for the United States to compete and cooperate with Japan as a technological superpower. The authors of the papers are of diverse intellectual and institutional backgrounds; they come from Japan, the United States, and Europe; and they represent academia, government, and private industry. The symposium sought to bring together experts in technology along with economists who have studied the economics of technological innovation, in the hope that the two groups of individuals could learn from each other and help inform a broader policy audience.

As a member of the Committee on Japan, I was pleased to serve as chairman of the symposium and as coeditor of this volume. My coeditors are Thomas Arrison and Martha C. Harris, both of the National Research Council's Office of Japan Affairs, and Edward M. Graham of the Institute for International Economics, all of whom (along with Maki Fife, also of the Office of Japan Affairs) worked with me to organize the symposium. Arrison and Harris authored the overview of the symposium included in this volume, which summarizes the principal conclusions of each of the papers. Graham contributed one of the papers as well as serving as coeditor of the volume. Dr. Erich Bloch, currently Chairman of the Committee on Japan, served as a commentator on the policy implications of the papers, and his remarks are included as the final chapter of this volume.

The symposium and this volume were made possible by grants from the Rockefeller Brothers Fund and the Bureau of Intelligence and Research of the U.S. Department of State. On behalf of the Committee on Japan, I would like to thank both of these institutions for their generous support.

C. FRED BERGSTEN, CHAIRMAN

NATIONAL RESEARCH COUNCIL SYMPOSIUM ON JAPAN'S GROWING TECHNOLOGICAL CAPABILITY: IMPLICATIONS FOR THE U.S. ECONOMY

Contents

Japan's Growing Technological Capability and Implications for the U.S. Economy: an Overview

Thomas S. Arrison and Martha Caldwell Harris

What are the present extent and nature of Japan's technological prowess? How will Japan's technological strength evolve in the future? What are the implications for the U.S. economy? This volume of papers authored by technologists, economists, and policymakers from the United States, Japan, and Europe contains varied perspectives on these questions. Their contributions in the chapters that follow should interest individuals, public and private, who are formulating technology policies in advanced industrial countries.

This volume is a compilation of papers first presented at a conference organized by the National Research Council's Committee on Japan as part of a larger program of activities designed to enable the United States to develop more effective ways of competing and cooperating with Japan as a technological superpower. Chaired by C. Fred Bergsten, member of the committee and director of the Institute for International Economics, the conference entitled "Japan's Growing Technological Capabilities: Implications for the U.S. Economy" was held on October 23 and 24, 1991, at the National Academy of Sciences.

The impetus for this volume, and the conference that produced it, comes from a belief that technological and economic perspectives on these issues are rarely joined. Thus, our goal was to incorporate insights from different disciplines and nations, especially Japan, and to explore the significance of Japan's growing technological leadership for global competition, particularly U.S. competitiveness.

CONTEXT

The passing of a world order dominated by two military superpowers naturally focuses attention on the character that international relations will assume in the years to come. A central question is how the three economic and technological superpowers (the United States, Japan and a united Europe) will interact in a world where bipolar military confrontation is diminished and where all major nations have elected the market as the preferred organizing principle for economic activity.

As C. Fred Bergsten noted in his opening remarks for the conference, two opposing tendencies are already apparent. First, opportunities for fruitful cross-border technological exchange and collaboration, particularly between private sector actors, are expanding at a rapid pace. These opportunities are driven by the globalization of markets. They are also strongly affected by another trend: the passing of U.S. technological preeminence and growing evidence that the United States lags Japan in terms of capabilities to commercialize civilian technology.

The globalization trend is already well developed among the industrial democracies and promises to broaden as more countries move toward open, market economies. In the foreseeable future, firms from the United States, Japan, and to some extent Europe are likely to remain in the forefront of international collaboration in research and technology development. Therefore, a deepening and acceleration of U.S.-Japan interdependence in technology is a particularly conspicuous aspect of the globalization of markets.

Yet while globalization would seem to suggest an inexorable movement toward a more integrated world economy and U.S.-Japan relationship, the growing divergence in the innovative and commercialization capabilities of countries may point in the opposite direction. Technology-related issues are increasingly prominent among U.S.-Japan economic frictions. The weakening or elimination of bipolar tensions has ushered in a period in which economic issues will rise on the agendas of the advanced, industrial countries. In the absence of the Cold War threat that held these countries together, conflicts arising from competition for technological and economic leadership will almost surely be more difficult to resolve under the rubric of common security concerns.

In short, we appear to be entering a world in which there is more potential for beneficial technological interaction among the advanced industrial nations but where the stakes and potential for conflict are also higher. Needless to say, the United States and Japan will play major roles in shaping the global cooperative and competitive context.

ASSESSMENTS OF U.S. AND JAPANESE TECHNOLOGICAL STRENGTHS AND WEAKNESSES[1]

Part I of this volume has a twofold purpose. The first is to present views of the countries' relative strengths and weaknesses by experts familiar with the technological capabilities of the United States and Japan. Together, these insights give us a "snapshot" comparison to serve as a baseline for the consideration of economic and policy implications that follows. The second purpose is to examine the methods for and applications of assessments of national technological strengths and weaknesses, particularly applications to policymaking.

The authors present a unanimous, unambiguous conclusion from their review of American and Japanese technological capabilities: while the United States retains leadership in software and in some other areas, Japan's technological capability across a wide spectrum of commercially significant fields is formidable and growing relative to that of the United States. By itself, this conclusion is not surprising. Over the past several decades Japanese companies have captured growing shares of the global market for numerous high technology products and have accelerated the pace of innovation in mature industries.

Besides agreeing on the specific technological strengths and weaknesses of the United States and Japan, the authors offer similar views on key aspects of Japan's technological strength. George Gamota points out that Japan's strength lies in the application of technology to products, while American companies are stronger in breakthrough research. In a similar vein, Jim Martin observes that the *laboratories* of U.S. universities or start-up companies are often ahead of any comparable technical effort in Japan, but Japanese companies still often enjoy more success in economically *manufacturing* related products.

Martin's observation reminds us that a meaningful assessment of the technology levels of the United States and Japan must gauge the likely effect of new technology on the production and distribution of goods and services. While the R&D laboratory is important, it is necessary to look beyond it to the commercialization and deployment capabilities of the respective national innovation systems and constituent organizations. For example, a firm will not employ a more efficient manufacturing process unless it possesses the necessary complementary assets, which include access to affordable capital, the availability of labor with the skills necessary

[1] The term "technology assessment" is used here and in many of the papers in this volume to refer to the process and results of analyses that compare and contrast national technological capabilities. It encompasses assessments of research, development, and deployment capabilities, although many analyses focus primarily on R&D capabilities.

to utilize the process, and managers who recognize the importance of innovation and marketing. Some assert that many U.S. executives face a structure of financial incentives that encourages short-term thinking, while the Japanese environment allows executives the longer time horizon needed for effective commercialization of laboratory research.

G. Laurie Miller makes the point that R&D in Japanese companies seems to be more closely tied to market developments than is often the case in American companies. Strong organizational links between market needs and the technology development function in Japanese firms not only speed technology utilization, but also have a deeper impact on the types of tasks emphasized in R&D. Miller argues that the "trial-and-error," market-driven approach to technology development taken by successful Japanese companies differs from the "scientific spin-off" model that has been more prevalent in the United States. In the scientific spin-off or "linear" model, basic research performed in universities and companies generates fundamental discoveries that firms then turn into products. In contrast, firms with a market-driven orientation stress incremental technology development, process improvements, and the construction of prototypes in product development. Effective technology commercialization usually incorporates both technology push and needs pull, but Miller asserts that the latter mechanism drives most innovation. He believes that Japanese firms typically recognize this and exploit it more effectively than do American companies. Miller believes that studies of Japanese technological capabilities yield diminishing returns and it is time for Americans to put knowledge about Japan to work by strengthening the links between research and the market.

The second purpose of the opening chapters is to consider the methodologies for and applications of assessments of national technological strengths and weaknesses as practiced in the United States and Japan. Recent publication of several critical technology lists in the United States attests to a growing interest here in identifying the technologies that are likely to have significant economic and national security impacts in the future, and in exploring how the United States compares with other countries in its capacity for developing and deploying those technologies.

George Gamota outlines the approach used by JTEC (Japan Technology Evaluation Center), which is probably the most prominent, continuing public effort in the United States to assess Japanese technological capability. JTEC, which is administered by the National Science Foundation, conducts several assessments annually that focus on particular technology areas and utilize a panel of U.S. experts. JTEC panels disseminate their results through workshops and by publishing reports that compare U.S. and Japanese technological capabilities.

Although JTEC studies usually focus heavily on technology development in R&D labs, the panels also evaluate manufacturing capability and other downstream assets. The assessments that have been performed over the seven years that JTEC has been in existence include many technologies that appear on critical technologies lists. Selection and assessment methodology reflect the interests of the line agencies, such as the Department of Defense or National Aeronautics and Space Administration that provide much of the funding for individual studies, rather than the commercial importance of the technology, though these considerations often overlap.

If Gamota could have his way, JTEC would be given the resources to do follow-up studies. It is unclear, however, whether JTEC studies have a significant impact on policymaking or on U.S. corporate strategy. Despite the presence of industry experts on the panels, awareness of the program in industry appears to be rather low. Jim Martin describes in-house programs of U.S. companies to monitor and access Japanese technology, and stresses the importance of an ongoing commitment and presence in the form of a liaison office or, preferably, an R&D lab in Japan.

Shigetaka Seki's description of the approach to technology assessment taken by Japan's Ministry of International Trade and Industry (MITI) in preparing white papers on industrial technology contrasts in some ways with the JTEC method.[2] The technology assessments summarized in MITI white papers are snapshots across a range of industries and technologies rather than a series of in-depth studies like those of JTEC.

Seki points out that it is natural that governments are concerned about whether their nation's vital industries can compete with industries of other nations. Technological capability is one of the factors that affects the competitiveness of industry. Technology assessment can give fundamental information to policy planners that they can use to develop appropriate policies.

For the 1988 white paper, MITI identified Japan's strengths and weaknesses in particular technologies and at various stages of research and development. The published aggregate results showed that in many fields the United States was strong in pure basic research while Japan showed more capability for improvement in R&D. These findings are consistent with those of Gamota, Martin, and Miller.

In the process of performing the assessment, MITI learned a great deal about the complexities and possible pitfalls encountered in performing technology assessments. Seki makes a significant contribution by discussing some of these issues in detail. Simple scorecards comparing overall performance can be misleading. The contribution of technology to competitiveness varies and depends on the aspect of technology that is under examination.[3]

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[2] See Tsushosangyosho (MITI), *Sangyo Gijutsu no Doko to Kadai* (Trends and Topics in Industrial Technology), (Tokyo: Tsushosangyosho, 1988).

[3] For example, Seki echoes Miller in pointing out that in the case of semiconductors, high productivity and quality may come from the accumulation of ordinal problem solving efforts rather than from new advanced technology.

Seki argues that there are no a priori objective criteria for selecting key technologies or predicting the future technological development capability of an industry or country. He points to the growth of technological partnerships among firms as another factor complicating technology assessment.

Nevertheless, technology assessment can produce valuable information, highlighting the manner in which innovative activities of different disciplines interact, the technological interdependence among industries and nations, and factors that stimulate the creation and diffusion of technology. In carrying out a technology assessment for its next industrial white paper, MITI selected 20 industrial products, based on the size of their respective markets rather than the technological sophistication of their products. Seki believes that technology assessment can contribute to better policymaking by clarifying which environments favor innovation and the extent of interdependence, thereby hopefully promoting greater harmony among national technology policies at an international level.

ECONOMIC IMPACTS AND IMPLICATIONS

The chapters focusing on assessments of Japanese and U.S. technological capabilities are followed by four that deal with the economic implications of Japan's growing technological capability—two devoted to macroeconomic and two to microeconomic issues.

In their contribution to the volume, Dale Jorgenson and Masahiro Kuroda present results of an extensive comparison of American and Japanese productivity growth in 29 industries for the period 1960–1985. In the model, differences in measurable productivity levels between U.S. and Japanese industries are defined as the technology component of differences in the relative price competitiveness of industry output. Jorgenson and Kuroda find that productivity growth in nearly every industry was faster in Japan than in the United States from 1960 until the first oil shock in 1973. Differences in industry productivity growth narrowed considerably after that as the rate of growth slowed in both economies.

Jorgenson and Kuroda conclude that technological competition has not played a determining role in generating visible manifestations of U.S.-Japan imbalance, such as the U.S. bilateral trade deficit with Japan. They further assert that technological competition between the two economies stabilized around 1980, when productivity levels of Japanese industries reached an average level of 87 percent of the productivity of U.S. industries. According to these authors, factors such as swings in relative labor costs and, most important, in the yen-dollar exchange rate have had a much greater impact than technology on competitiveness, defined as the relative price of delivering the same product in the two economies expressed in a common currency. Although the productivity analysis only considers the period through

1985, the improvement in the U.S. external position achieved since the fall in the value of the dollar after October 1985 illustrates this point. Jorgenson and Kuroda draw the conclusion that technology is not a major explanation for U.S.-Japan trade problems.

Masaru Yoshitomi, the other contributor to the discussion of macroeconomic issues, has a different perspective that in some ways complements and in others diverges from that of Jorgenson and Kuroda. Yoshitomi asserts that in the 1980s, productivity in Japanese manufacturing advanced at a pace that rivaled the performance of the rapid growth period of the 1960s. He attributes this result to significant increases in R&D spending and other investment on the part of Japanese firms. R&D spending increases and other activities associated with accelerated innovation were in turn motivated by fierce rivalries among firms. According to Yoshitomi, industry rivalries, the resulting innovations motivated by the pursuit of temporary "extra profits," and the beneficial spillovers from R&D spending in one industry to the productivity of other industries through input-output relationships are all keys to the "Schumpetarian" character of the Japanese economy.

Yoshitomi holds that whenever an economy, like Japan's, is marked by Schumpetarian competition, it can experience rapid upgrading of its resource endowments and shifts in the structure of comparative advantage that determines its trade. Therefore, innovation can have an impact on the dynamic trade performance of an economy even if trade at any given time conforms to notions of Ricardian static efficiency.

There are several apparent differences between Jorgenson/Kuroda and Yoshitomi, some of which diminish on closer inspection. The first concerns the impact that innovation has had on Japan's trade. Jorgenson and Kuroda say that the impact has been small, while Yoshitomi asserts that it has been significant. This disparity is not as great as it appears, since the two papers are answering different questions in this respect. Jorgenson/Kuroda and Yoshitomi might agree that a country's trade balance at a given time is determined largely by macroeconomic factors, but that the rate and level of innovation in an economy and in particular industries will significantly affect the composition of exports and imports without necessarily affecting the trade balance of the nation.[4]

The two papers also contain different perspectives on productivity growth in Japan during the 1980s, with Yoshitomi giving a much more favorable assessment than Jorgenson and Kuroda. Part of this disparity may be due to the time periods covered. Yoshitomi includes developments up to 1988,

[4] John Cantwell, in another paper included in this volume, argues that the technological capabilities of a country's firms can have an impact on the trade balance and other macroeconomic indicators. Cantwell's reasoning is summarized in more detail below.

when appreciation of the yen had intensified the struggle for efficiency and innovation in Japan's manufacturing sector, whereas the Jorgenson/Kuroda analysis ends in 1985. Yoshitomi also emphasizes overall manufacturing productivity growth in contrast to the focus on average productivity growth over 29 manufacturing and nonmanufacturing industries by Jorgenson and Kuroda. If Yoshitomi is correct, the overall technological gap that Jorgenson and Kuroda say stabilized around 1980 may have begun to narrow once more. Fundamentally, this is an empirical issue that should be clarified by further research.

There are also basic, theoretical questions worthy of attention in the future. Jorgenson and Kuroda would likely attribute the strong growth performance of the Japanese economy during the 1980s to high investment levels (i.e., to higher levels of capital input into the production function rather than to a more efficient use of those resources). In Yoshitomi's view, there is an intimate relationship between innovation and capital investment. A closer comparison of the empirical tools that Jorgenson/Kuroda and Yoshitomi use to distinguish between the effects of more capital and more *efficient* capital might yield interesting results.

The most significant differences in outlook between the two papers are revealed in subtle extrapolation rather than clear disagreement. A closer look at Jorgenson and Kuroda's findings reveals that, while overall productivity growth between the United States and Japan converged after the first oil shock, the U.S.-Japan variance in productivity growth in particular industries has increased. For example, in the electrical machinery industry, Japanese productivity has surpassed the U.S. level and is continuing to pull away, while the United States has maintained or increased its productivity lead in agriculture.

While Jorgenson and Kuroda document these differences, Yoshitomi appears to give greater weight to their macroeconomic impact. In emphasizing the spillover benefits of R&D performed in one industry to other industries, Yoshitomi explains that the transportation and the iron and steel industries were particularly receptive to these benefits in the 1980s. Although it is not directly stated, it follows that if there are industry differences in the receptivity to spillover, there should be differences in spillover generation as well. If a high level of innovation in an industry such as electrical machinery has a greater impact on the macroeconomy through spillover than an industry such as agriculture, some would conclude that the spillover-generating, "strategic" industries should be supported by government policy. Once again, some of the theoretical questions at the root of this issue are amenable to empirical inquiry. If some industries are generally seen to contribute more to economic growth and if Japan enjoys higher productivity growth than the United States in the bulk of them, it should eventually show up on the bottom line of overall productivity growth in the two economies.

In the papers dealing with microeconomic issues, the difference in perspectives is less complex and more complementary. The chapter authored by David Mowery and David Teece has two components. The first is a comprehensive literature and statistical survey that lends further support to the consensus of the authors in the first section that the technological capabilities of Japanese firms are increasingly formidable. Mowery and Teece show how the commercial focus of Japan's national innovation system has a major positive impact on the ability of Japanese firms to develop and utilize technology.

The second component is a discussion of the most prominent mechanisms for growing U.S.-Japan private sector technology collaboration and an evaluation of the policy implications. The mechanisms include the overseas R&D labs of multinational corporations and U.S.-Japan corporate strategic alliances. Mowery and Teece conclude that these mechanisms are not a significant cause of unbalanced technology flow between the United States and Japan. They assert that the visible consequences of alliances and Japanese direct investment thus far do not support the critical view put forward by some analysts. Therefore, the authors conclude, policies aimed at restricting Japanese investment and U.S.-Japan technology linkages are not likely to help the competitive fortunes of U.S. firms.

In presenting their views on the likely impacts of various types of U.S.-Japan technological interactions, Mowery and Teece point out that the information base for considering these issues is inadequate. Given the uncertainty that remains over the extent to which Japanese "transplants" are contributing to the technological skills of the U.S. work force and suppliers, as well as the lack of data on establishment-level R&D activities and other aspects of Japanese direct investment, there is a strong case to be made for more research and analysis on these questions.

In the other paper dealing with micro issues, William Finan and Carl Williams present a case study of how Japanese electronics companies are moving to overcome a perceived technological deficiency—the lack of adequate human resources to match U.S. strengths in software engineering. They focus on a subfield of software engineering, the development of integrated circuit computer-aided design (IC CAD) tools for use in the semiconductor industry. Finan and Williams conclude that in IC CAD, Japanese companies will have to supplement their traditional approach to building strength in critical technologies, which is to build capability in-house through training and college recruiting. The authors anticipate that Japanese electronics firms will be forced to resort to lateral hiring, recruiting from second-tier schools and building research labs offshore in order to build the necessary capability. These new imperatives and tactics will have important consequences for the future of Japanese management. Finan and Williams also point out the implications for U.S. companies, which will face competition from Japanese firms in the U.S. market for software engineers but may find it easier to hire skilled Japanese engineers laterally as Japanese corporate culture becomes less tightly knit.

FUTURE OF COMPETITION

Part III of this volume consists of three chapters on future trends in U.S.-Japan technological competition and their wider implications. Edward Graham focuses on a phenomenon mentioned by Mowery/Teece and Finan/Williams: the growing number of Japanese-owned R&D facilities in the United States. Graham surveys the literature on the subject, examines the most recent data, and considers the likely motivations and distribution of benefits associated with Japanese-controlled R&D labs in order to answer the question of whether Americans should be concerned.

His analysis indicates that the available data do not provide a basis for drawing firm conclusions. To the extent that Japanese-owned R&D in the United States provides a channel for increased Japanese contributions to open, basic research, Graham argues that these firms should be welcomed except for a few cases of legitimate national security concern. Basic research generates more "downstream" and "external" benefits that accrue to users of the firm's products and society at large than does proprietary product development. Graham believes that Japanese-owned research facilities in the United States will provide considerable benefits to Americans. It will be interesting to see, in the years ahead, whether Japanese firms performing R&D in the United States opt for more fundamental research or pursue the typical approach—emphasis on proprietary research to spark new products and increased sales. Graham argues that even proprietary R&D performed by Japanese companies in the United States generates external and downstream benefits. The key question here is whether the activities are "additive" (additions to overall R&D performance above what would otherwise have been performed by American-owned firms) or whether they displace equivalent R&D under U.S. ownership. Overall, however, Graham expresses doubt that Japanese-owned R&D laboratories raise significant cause for U.S. concern.

The authors of the other two chapters in this section present theoretical arguments on how changes in innovation paradigms will affect global technological competition. The approaches taken by both John Cantwell and Fumio Kodama are informed by the Japanese experience, but they display interesting differences in emphasis.

Cantwell argues that between the 1960s and the 1980s a change occurred in the technological paradigm characterizing commercial innovation. A technological paradigm is a "widespread cluster of innovations that represent a response to a related set of technological problems, based on a common set of scientific principles and on similar organizational methods." When a paradigm changes, technological leadership passes to the country whose social institutions are best suited to the new approach. According to Cantwell, the United States was the pacesetter for the technological paradigm that arose during the interwar period, which was characterized by opportunities in energy and oil-related technologies. With the advent of the current paradigm, in which the most promising opportunities for innovation are in microelectronics and computerized systems, leadership has passed to Japan. Cantwell holds that it is impossible to predict when or where the next paradigm will arise, but Japanese industry and the leading Japanese firms may well continue to outperform American companies as long as the current paradigm stays in place.

There are several other aspects of Cantwell's argument that deserve comment. First, he asserts that innovation by Japanese firms has played a major role in producing Japan's large, persistent trade surplus.[5] Since the difference between any country's exports and imports is equal to the difference between domestic saving and domestic investment, Cantwell must explain why Japan's savings persistently exceed investment. He asserts that a country such as present-day Japan that is innovating rapidly (as a result of its fit with the prevailing technological-economic paradigm) will see productivity gains and corporate profits outstrip wage increases. Since the recipients of profit income have a higher propensity to save than the recipients of wage income, consumption growth in a leading economy of a technological paradigm will tend to lag income growth, and savings will tend to exceed investment.

Cantwell's second point concerns policy implications for the United States. He does not believe that it would be possible for the United States to adapt its institutions to the opportunities of the current paradigm through government policy alone. He does believe that technology policy measures may be necessary to prevent the United States from falling further behind.

Fumio Kodama also sees a new technological paradigm emerging. Rather than emphasizing a shift in opportunities from one set of technological fields to another, Kodama asserts that the emerging paradigm is characterized by a closer interdependence between innovative activities in different fields. This technology interdependence, or "fusion," is illustrated by Japan's prominence in mechatronics (the fusion of mechanical and electronic

[5] Under traditional open market trade theory, however, a large and consistent current account surplus should induce appreciation of the surplus nation's currency that will drive the nation toward external balance. Why this did not occur as rapidly for Japan remains an open issue.

systems) and optoelectronics (the fusion of optics and electronics). Technology fusion is accompanied by shifts in organizational and policy imperatives. At the firm and industry level, technology fusion necessitates a shift from "producing" to "thinking" companies (companies that spend more on R&D than on capital equipment), a shift from a single to multitechnology base, and a shift from linear to "demand articulation"-driven technology development (essentially a shift from technology push to needs pull as discussed above).

Although Kodama's title implies that Japanese firms are uniquely situated to take advantage of the new paradigm because of their success in technology fusion, he does not emphasize this point in his paper. Instead, he draws the policy inference that research and development consortia that include companies from a range of industries are an effective means of constructing the "innovative infrastructure" necessary to exploit technology fusion. He argues that excluding foreign firms from these consortia would be counterproductive to national technology policy.

Taken together, Cantwell and Kodama make a number of provocative arguments and raise some interesting questions that deserve further study. Cantwell's analysis, for example, raises a basic "chicken and egg" question. Did a shift in the technological paradigm present opportunities that Japanese firms are better organized to exploit, as Cantwell argues? Alternatively, did the dynamism of Japanese firms allow them to blaze an innovative path with somewhat different characteristics than the one that American companies were previously following in the same industries, thereby creating the new style of action that the new paradigm embodies? Which came first, the paradigm or the ability of Japanese corporations to take new approaches to innovation broadly defined?

Kodama's analysis raises questions as well. Future research may clarify the degree to which elements of the technology fusion paradigm are really new and the degree to which they are constants of successful innovation. The parallels between demand articulation as described by Kodama and "Edisonian incrementalism" as described by G. Laurie Miller earlier in the volume may be instructive in this sense. In short, new paradigms governing the course of technology development and its relationship with economic growth and national prosperity may be operative. However, the specific mechanisms and relationships that characterize paradigms and the laws governing shifts from one to another are key issues that demand further elaboration. The contributions by Cantwell and Kodama are excellent starting points for organizing such an effort.

POLICY IMPLICATIONS

Richard Nelson frames the discussion of policy implications for the United States by focusing on five issues that bear on the relationship between the relative technological capabilities of the United States and Japan and their economic implications. The five issues are (1) the convergence in technological capabilities of major industrialized nations since the early postwar period; (2) the comparatively slow growth in U.S. productivity and incomes since the early 1970s; (3) the loss of U.S. comparative advantage in "strategic industries;" (4) the complexity of national institutions and policies supporting the development of technology; and (5) the impact of the internationalization of business on policy formation.

Nelson draws an important distinction between long-term convergence in the technological capabilities of the major industrialized nations and the slowdown in productivity growth experienced by the United States. These two trends are often linked but, according to Nelson, may not have a great deal to do with each other. The loss of the special advantages that the United States previously held in strategic industries is another secular trend.

Nelson argues that formulating appropriate policies is an increasingly difficult undertaking for two main reasons. First, national institutions that support technology development are complex, so determining whether various types of government involvement are appropriate and fair under international rules of the game is no simple task. Second, the internationalization of business is making it more difficult to target or predict the impact of technology policy measures on national firms in advance. Governments that want to help "domestic" firms find it increasingly difficult to define them and their products.

Despite these caveats and considerations, Erich Bloch and Hiroshi Ota add their perspectives, as individuals involved in the policymaking processes in both countries, on the implications for the United States. [6] The degree of agreement between the two is somewhat startling. Both believe that the technological leadership of the United States is eroding and that a continuation of current trends could have serious and unfavorable consequences for the American and global economies. Both believe that the United States should formulate an explicit technology policy as part of a more vigorous program to restore the competitiveness of the U.S. economy. Both also call on Japan to take a more proactive stance toward adapting its institutions and business practices to international norms, and Ota suggests that an appropriate level of U.S. pressure in this respect is productive.

Bloch outlines his perspectives on the problems and causes faced by the United States, proposes areas for policy change, and also points out what America and Japan can do together to manage the technological aspects of

[6] See also Erich Bloch, "Toward a U.S. Technology Strategy: Enhancing Manufacturing Competitiveness, Manufacturing Forum Discussion Paper 1" (Washington, D.C.: National Academy Press, 1991) and Hiroshi Ota, *Kuzureyuku Gijutsu Taikoku: America no Jigazo* (The Crumbling Technological Superpower: America's Self-Portrait), (Tokyo: Simul, 1992).

the bilateral relationship. Ota outlines some of the elements that he would *not* like to see in a U.S. technology policy: the exclusion of foreign firms from U.S. government R&D consortia, restrictions on inward direct investment, and other measures he terms "technonationalistic." By arguing that such measures would hurt rather than help U.S. competitiveness, Ota echoes Mowery/Teece, Kodama and Graham.

The question of whether the United States needs to make substantial policy changes in order to remain a front-line player in global technology development and in the world economy during the coming century is the most significant theme underlying the papers in this volume and the discussions at the conference.[7] The views of technologists, economists, and policymakers add valuable perspectives to the consideration of this question. The Japanese experience is directly relevant for two obvious reasons. First, Japan's technological and economic strength will have an important impact on the world economy and on the United States. Second, Japan's success challenges assumptions of U.S. policymakers at different points on the political spectrum—both those who question whether government policy can accelerate the pace of innovation and those who advocate a more activist technology policy.

Differences in emphasis that emerge in the following chapters are related to alternative explanations of Japan's economic and technological performance. Some of the authors attribute the performance mainly to the higher savings and investment rates achieved by the Japanese economy. Indeed, many economists would say that superior management of the macroeconomy by the Japanese government has played the major role in sustaining a high investment rate, which has led to a fast turnover of capital stock.

Other contributors postulate that a better fit between the organization of Japan's economy and an emerging technological paradigm has made a significant contribution to performance. Viewed from this perspective, the key question is what role policy has played in "fitting" the Japanese economy to the paradigm. It is likely that both high rates of investment and changes in the character of innovation have contributed to some extent.

While Japan's sectoral policies of the past are well documented, the current extent and relevance of Japanese industrial policy constitute a subject of debate. From a historical perspective, the unique contribution of Japanese industrial policy is difficult to determine because Japan's macroeconomic management during the postwar period has been exceptional. Apart

[7] The United States has a technology policy, that has traditionally been structured to support specific goals, especially national security and public health. There have been increasing calls for the U.S. government to refocus technology policy on fields more relevant to commercial competitiveness.

from a brief period of large budget deficits during the late 1970s and early 1980s, Japanese monetary and fiscal policy have encouraged low inflation and high saving. Japan's industrial policy, including its technology promotion measures, would not have worked as well in a poorly managed macroeconomy. It has been about 20 years since the American economy has had stable prices and a balanced budget simultaneously. These two decades of fiscal imbalance coincide with slower productivity growth in the U.S. economy.

Though difficult to quantify, there is considerable evidence that Japan's technology and industrial policies have had positive impacts on the economy. This experience is relevant for the United States today. Japan, a major competitor and a country that developed effective industrial promotion policies, offers some interesting examples in its adaptation of policies to new international market forces. Japan's technology policy today, with its emphasis on technology fusion and the globalization of technology, is a far cry from the sectoral industrial policies of years past.

Both government and industry in Japan are actively promoting strategic alliances, and a variety of new forms of international technology linkage—such as inviting foreign participation in Japanese government-sponsored R&D and building ties to foreign research institutions. When such technology linkages are considered together, interaction with Japan is as intensive (perhaps more intense) as that with any other country in key fields. The Japanese government is working with Japanese and U.S. companies to restructure important bilateral technological linkages.

It is important to note the emergence of a debate in Japan over the distinctiveness of Japanese-style capitalism and whether special efforts are needed in order for Japan to enjoy good relations with the United States and the rest of the world. This debate is marked by disagreement over whether Japan has a responsibility to bring its market system closer to those of the United States and others, or whether the responsibility for change lies elsewhere. Sometimes explicit and sometimes implicit are concerns about the unfortunate political repercussions likely to arise if the patterns of the past (technology transfer from the United States to Japan, growing Japanese dominance in some important high technology industries, and laggardly Japanese government funding of more fundamental research) persist. The conscious effort now under way in Japan to restructure technological linkages suggests the continuing importance of public and private policy in Japan and the need to relate domestic technology policy to larger global market trends.

These observations also provide reinforcement for those who call for new attention to technology policy in the United States. What might a U.S. technology policy directed at promoting innovation in a changing international context look like? How might three elements identified in some of the papers in this volume—diffusion, human capital development, and a new organizational and analytical approach to policymaking—be woven into new approaches? These observations cannot be answered in detail here, but some observations are suggested by themes in this volume.

Policies for technology diffusion, to be effective, must extend beyond technology developed within the United States (for example, from universities to industry) to the application of technologies and production techniques developed in Japan for the benefit of the U.S. economy. Japanese companies are well known for capitalizing on technology developed externally—including technology developed in the United States—and policy has played a role. Many excellent U.S. companies use technology developed externally, but only a small percentage of the largest firms have the resources and motivation to systematically monitor and actively acquire Japanese technology. A key question is whether policy can help U.S. companies develop a "fast second" approach that facilitates reentry into industries such as consumer electronics, which have broad spillover effects for electronic components, computers, and telecommunications equipment. Policies that promote diffusion will be more effective if they contribute to developing mechanisms for tapping into the expertise and resources of Japanese firms doing business in the United States as well as Japan.

In working to upgrade U.S. capabilities to use technology more effectively to produce internationally competitive goods and services, policymakers will need to consider incentives for foreign-based firms that contribute significantly to the U.S. economy through technology transfer, training, and advanced production and R&D. Some would argue that foreign-based companies that thus contribute to the U.S. economy and technology base should be invited to participate in U.S. collaborative R&D projects. Cooperative programs by U.S. industry to monitor and diffuse technology developed in Japan may be another avenue worthy of consideration. The papers authored by Gamota and Martin indicate that Japanese technical information is plentiful and strategies for acquiring Japanese technology can work for U.S. companies that build the organizational resources necessary to access and use it.

Policies aimed at promoting the acquisition of skills by Americans that would facilitate a stronger flow of technology from Japan to the United States would complement steps suggested above. Training of technical personnel in the Japanese language and in Japanese management practices is a step in this direction as are internships for young U.S. engineers that give them firsthand experience with Japanese manufacturing practices. To the extent that U.S. universities and industry develop mechanisms for cooperation with foreign firms that build in reciprocal access to Japanese manufacturing technologies and practices, the result should be to increase technology transfer from Japan to the United States.

No matter how well conceived and implemented the particular measures might be, they will not be effective in the absence of a new organizational and analytical framework for civilian technology policy and deep understanding of new trends in the globalization of technology. Many of the papers in this volume point to the need for improved capabilities to assess the future of industries important to the U.S. economy, to identify technologies that will have broad impacts on many industries, and to develop a U.S.-style vision or notion of the desired industrial structure of the future. Understanding of new developments in Japan and around the world and the ability to integrate domestic technology policy with international economic policy are other key imperatives suggested from our reading of the papers.

It is clear that U.S. technological preeminence has passed, that U.S. technological leadership is eroding in many fields, and that Japan will be a major competitor and collaborator in the future. The challenge for U.S. policymakers is to come to terms with the two trends outlined at the outset—growing international collaboration in technology and greater friction over growing national disparities in their capabilities to profit from innovation. In order for the United States and Japan to reap the benefits of the first trend, it will be necessary to take steps to arrest the second. A continued erosion of America's capability to reap economic benefits from innovation relative to Japan and other countries would have adverse impacts not only on the United States, but also on Japan and the global economy. The question is whether the United States can develop effective policies to both compete and cooperate with Japan as a technological superpower. Hopefully, this volume will contribute to the clarification of the issues and the formulation of responses.

I

ASSESSMENTS OF U.S. AND JAPANESE STRENGTHS AND WEAKNESSES

Technology Assessment in the U.S.-Japan Context

GEORGE GAMOTA

INTRODUCTION

At first glance, Japan hardly can be found on the globe—a series of small islands scattered along the Eastern side of Asia, stretching for almost a thousand miles. However, economically speaking, Japan's technological and industrial shadow covers the globe, and economically it is the second largest power in the world, the largest still being the United States. Japan's land mass is approximately the size of California, although its useful land comprises only a third of that due to rough, mountainous terrain. The population, estimated to be 123 million in 1989, is almost exactly half that of the United States.

Japan was not always an economic superpower. In the late 1950s and early 1960s, Japan was a poor country having few, if any, natural resources, still recovering from the devastating effects of a world war. Worldwide, Japanese products were synonymous with inexpensive and unreliable trinkets and toys, but not for very long. Japanese products continued to be inexpensive, but at first products such as cameras and calculators, then electronics, and finally automobiles, became the standard by which the quality and price of all products were being judged. Much of the success of the Japanese can be traced to their investment in technology, long-range view of return on investment, leverage strategy of market penetration, and just plain hard work. Their products were not magic; in fact, most if not all of the early technology in those products originated in the United States.

In the years following World War II, the Japanese came to the United

States to look at our factories and how we manufacture. Now, we go there to look at their production lines. The Japanese have also come to look at our technology, but now is the time for Americans to look and learn from Japanese technology. In a global environment, no country can sit idly by and ignore the rapid progress being made in other countries.

The Japanese appreciate the importance of information. They have almost a passion for information of all kinds. They love studies and they believe in making assessments, quantitative comparisons of all kinds of factual data. Much more than in the United States, the Japanese believe in, and use, statistical data to make predictions. I was particularly impressed by their use of the Delphi method to make predictions. A good example is *Future Technology in Japan-Forecast to the Year 2015*. It was published by The Institute for Future Technology (4th technology forecast survey of the Science and Technology Agency (STA)). It is updated regularly, with the last version being printed in 1988.

The closest parallel to this work in the United States is the annual critical technologies report issued by the Department of Defense. However, no such unclassified report existed prior to 1989, while the Japanese have been publishing their reports for at least 15 years. Unlike us in the United States, the Japanese spend much time and money learning what others are doing. In fact, they are proud of the type of assessments they are able to make of other people's work, and often have chided us for not paying attention to their work. One of the surprising comments made to me by a Japanese colleague back in 1984 when I started the Japanese assessment program called JTEC, was "It is time that you Americans are starting to pay attention to what we are doing. We have been following your work for some time now, but you don't even pay attention to our technical journals published in English."

Just how interested the Japanese are in foreign technology is illustrated in Table 1. The data was published in 1987 by the General Affairs Agency

TABLE 1 Trade in Technology Information in 1987 (million dollars)

	From Japan	To Japan
United States	479	1,343
Western and Eastern Europe	335	654
Asia, and other continents	746	<30

NOTE: Technology information includes all forms of information transfer: books, journals, newspapers, video and audio tapes, and compact disks.
SOURCE: Wall Street Journal, November 14, 1988.

of Japan. Japan purchases nearly three times the amount of technical information from the United States than does the United States from Japan. Japan has negative trade in technology information only with Third World countries.

Gaining information about Japan is actually not very difficult. One of my preconceived notions about Japan and the ability to gain information was that Japan was a closed society, that the best work was published in obscure Japanese journals, and that the technical community was unwilling to share its results with the rest of the world. After eight years of being intimately involved in technical exchange, I have come around 180 degrees in my thinking. I believe there is more information available on Japanese technology—in English—than we can honestly hope to use effectively. The problem is not its availability or access but our desire and willingness to delve into that resource and utilize it more fully.

For example, there is a publication circulated by the Japan Center for Information and Cultural Affairs that provides a list of English publications by various Japanese government and quasi-government organizations. The title is *List of Foreign Language Publications by Japanese Government and Related Organizations*. Under government organizations, there are 23 divisions. Under the Ministry of International Trade and Industry (MITI), there are 17 publications listed. Included are such reports as *Obtaining Industrial Property Rights in Japan; MITI* (which includes a description of the agency, what it does, and advice on how to do business with it); *Statistics on Japanese Industries* ; etc. Under the Ministry of Construction, there are 43 reports in English. To obtain many of these reports, all one has to do is go to the government bookstore, which is located across the street from MITI in downtown Tokyo, or order them directly from the agency by mail.

At this point, I would like to share with you the background of how I got involved in assessments, particularly assessments of Japanese technology. By training, I am a physicist who, after eight years at Bell Laboratories as a scientist, went on to serve in the federal government. My last position there was Director for Defense Research; that is, I had overview responsibility for all the research being sponsored by the military departments. During my nearly six-year tenure there, one of the most pressing problems was identifying and assessing foreign technology. Quite frankly, our information was inadequate. I am not referring to information on weapon systems. Information on that was quite good, but reliable knowledge and understanding of the status of foreign technology were lacking, whether it be European, Soviet, or in particular, Japanese.

The requests for this type of foreign technology information come from many sources. Let me give you a typical example. The president makes a visit to some foreign country, and an agreement is made to cooperate in technology. The country in question has a specific agenda in mind, whereas the United States generally has no clear goals. Once the president returns home, a call from the Office of Science and Technology Policy (OSTP) goes out to poll all agencies about what they know of that particular country and asks what areas the agencies want to cooperate in. While this process produces many inputs, most of these inputs are on-the-spot assessments. Some might be good, whereas others are impressionistic judgments based on memory rather than on reliable sources of information. Since all of this is done at the last minute and is a reaction to a specific request, once the drill is over, people, including me, go back to what they were doing before and forget about this problem until the next time.

Unfortunately, this problem did not disappear but became worse as we all started to realize that U.S. technological superiority was shrinking, and foreign technology was becoming increasingly important. Japanese technology, in particular, started to emerge as singularly important in the impact it had on the U.S. economy. Unfortunately, identifying this as a problem is not synonymous with solving it, particularly if the problem is so pervasive that it is viewed as everyone's problem, yet not high enough on a priority list to be considered any particular agency's problem.

In late 1982, after numerous discussions at various agencies, I got the attention of the Commerce Department. This was significant since Commerce generally has limited resources and its personnel turn over so rapidly that it is usually difficult to attract someone's attention, have that person do something, and still be around to see it implemented. Fortunately, at that time there was a lineup of people who understood the problem and were eager to solve it. They included the following: Lionel Olmer, Clyde Prestowitz, and William Finan from Commerce; John McTague and Maurice Roesch from OSTP; and Frank Huband from the National Science Foundation (NSF). Thus the Japanese Technology Evaluation (JTECH) program was born. Commerce initiated an interagency effort to assess and evaluate Japanese technology on a continuing basis. The birth of JTECH was not as smooth as we would have liked. By the time all the wheels of the procurement process were in place and interagency coordination was completed, nearly half of the proponents were gone, and for a while it looked as if JTECH would be stillborn, or die in its infancy. Thanks to OSTP and NSF, the program survived and has had a fairly good base of support since at least 1987.

In an eight-year span, the JTEC[1] program has completed over 22 studies of Japanese technologies. Each JTEC study is, by itself, a composite, in-depth look at the current state of a particular Japanese technology. It is also a snapshot in time of a particular technology and its relationship to a possible range of products. Since the intent is to look at Japanese R&D from the Japanese rather than the American point of view, the JTEC panels are usually made up of an interdisciplinary team headed by a chairperson who has broad knowledge of the subject.

We in the United States are often very compartmentalized, whereas the Japanese are known for their teamwork; thus we try to emulate "their team" in our panels. Typically, the life of the panel continues past its JTEC responsibilities, which end with the publication of a report. Several panels have held special sessions at technical association meetings to discuss their findings and have published articles in leading technical magazines. Results have appeared in the popular press. For example, the results of the nuclear power panel's work appeared in *The New York Times*. These activities are intended to encourage more scientists and engineers to recognize the importance of monitoring Japanese technical developments on a regular basis.

As part of the process, comparisons are made with U.S. programs whenever possible to provide benchmarks.[2] JTEC also encourages the panel members to go beyond reporting ongoing research activities and to discuss the significance, either scientific or commercial, of those activities. Finally, the panelists are asked to discuss the direction in which the work is going and the rate of change. Each panel chairman is asked to assemble a chart summarizing Japan's current capability and rate of change. A sample chart is shown in Table 2. This summarizes the assessment carried out recently by the advanced computing panel.

Some have criticized this type of reporting as being simplistic. While I agree that such a chart could be misinterpreted or, worse, used sometimes in a manner that it is not intended for, the positive virtue overwhelms the negatives. First, it forces the technical community to summarize its assessment in a manner that the lay community can better understand. Living in a headline-driven society, the technical community must adapt to society as a whole; otherwise, our advice will not be heeded, and we will not be understood. JTEC's purpose is not only to educate and make U.S. researchers aware of foreign technology, but also to help educate the American people in science and technology.

The reports are reviewed both in the United States and in Japan. Early on in the JTEC process, we learned that the best way to ensure accuracy is to let the Japanese experts review our drafts. Some might argue that this could compromise the assessments. Nothing could be further from the truth. It actually makes the reports more accurate since both the reviewer

[1] The name was changed slightly, from JTECH, to JTEC, when NSF set up a center at Loyola College. JTECH was managed by Science Applications International Corporation.

[2] For example, in the superconductivity report, a comparison is made of U.S. and Japanese work on digital and analog electronic devices, and predictions of their success in applying the technology for commercial purposes.

and the author know that the work is going to be scrutinized by the other. In case of irreconcilable differences, the author's statement stays, but the reviewer's comments are recorded in a footnote.

TABLE 2 The Overall Comparison between U.S. and Japanese Advanced Computing Technology

Area	Position	Rate of Change
Electronic components	+	↑
Data storage	O	↑
Computer architecture	-	↗
Software	-	→
Scientific calculations and supercomputers	O	↗
Computer/human interface	-	↘
Multimedia	+	↗

NOTE: A plus (minus) means that Japan is ahead (behind) the United States; ↑ means that Japan is pulling away from the United States, while → means that the relative position is not changing; O means that the United States and Japan are roughly equal.
SOURCE: M.A. Harrison, E.F. Hayes, J.D. Meindl, J.H. Morris, D.P. Siewiorek, R.M. White, *Advanced Computing in Japan*, JTEC, 1990.

A JTEC study is staffed by a panel of experts, a different group for each technology, and has been coordinated for the last several years by Loyola College in Baltimore, Maryland. The principal investigator at Loyola is Professor Duane Shelton and the current NSF program director is Paul Herer of the engineering directorate. The panel of experts is specifically tasked to stay within the boundaries of its expertise. Panelists are not to deal with broader political or economic issues that they have views on, because they may lack experience or have strong biases. What is desired is a solid technical assessment backed by firsthand knowledge. It is up to government policymakers, not outside experts, to make specific recommendations. The experts can best serve by providing us with the best information upon which the policymakers can base decisions.

Beyond government, the main customer for the JTEC technology reports is the U.S. R&D community. This includes universities, "not-for-profits," and industry. One could argue that industry has other means of obtaining this information and therefore it is not needed. After all, there are a large number of U.S. companies that have set up listening posts in Japan. Why duplicate the effort and spend U.S. taxpayers' money on it?

The answer to this is very simple. U.S. industry generally, like the U.S. government, looks at things from a near-term perspective and does not invest in the kind of work that the Japanese particularly excel in—

information gathering. Additionally, while large companies might be able to invest in foreign outposts, small-and medium-sized companies do not have the resources.

One sign of this need is the overwhelmingly positive response from industrial people interested in participating in the panels. Participation is not an honorary title; it means hard work on the part of the panelists, probably four to six weeks of their time. AT&T Bell Labs, IBM, Apple Computer, Hewlett-Packard, MCC, and Rockwell are just a few of the corporations that have provided some of their top technical experts to participate in this program.

By participating, panelists put in a lot of time and put their reputations on the line. Each panelist has to write his or her own evaluation and is bylined as an author. This is not an assessment in which a panel is formed, comes to Washington to spend a day or two discussing a topic, and leaves, and then a staff person picks up the pieces and writes a summary essay. That process might be adequate on topics in which a panelist is, in fact, an expert and has firsthand knowledge. However, in areas where people do not have firsthand knowledge, this is a potentially dangerous method of assessing technologies and their implications, and often leads to serious misconceptions about the real situation.

Experience with JTEC shows that respected American technologists often begin with biased viewpoints and change their attitudes after their trips to Japan. I have two examples in mind: one involves a respected expert from a prestigious university, and the other a senior technical manager from a premier industrial laboratory. Both people were reluctant to join the team since they felt they already knew what was going on. Upon visiting Japan, their attitudes changed completely. The industrial person, prior to JTEC, had been in Japan once and, since his JTEC experience, has been going there at least twice a year and has continued his contacts.

Several studies (i.e., in the area of computer science) have been repeated due to the great interest in the subject as well as the rapid changes in the technology. Because of the continuity and corporate memory of several individuals involved with the JTEC program, it is now possible to assemble a fairly good picture of the progress of Japanese technology development and commercialization and compare it to that in the United States. Because of the time span between the earlier reports and the current studies, it is also possible to see which of the predictions made came through, which ones did not, what was missed, and, finally, why some predicted events did not come to pass. The Institute for New Generation Computer Technology (ICOT) Fifth Generation project, for example, is considered by many to be a disappointment, although I personally feel that while it did not achieve all its goals and some predictions did not come to pass, it did teach the Japanese many things that are critical to the next phase of advanced computing. The

1987 study on advanced computing dealt almost exclusively with the Fifth Generation program, while the 1990 study reflected on the successes and failures of that project.

According to a study done by Cecil Uyehara, JTEC has performed about half of the openly available government-sponsored studies on Japanese technologies.[3] I have organized the executive summaries into groups of related technologies to provide some perspective on the wide range of studies undertaken by JTEC. This will allow the reader to make correlations more easily between similar areas and to compare changes reported by similar studies done at different times. I have chosen the National Critical Technologies List as a template for grouping the JTEC studies.[4] That list is comparable to some of the other lists currently being utilized. For example, other studies include the Department of Defense (DOD) *Critical Technologies Plan*,[5] the Department of Commerce list, the Council on Competitiveness list, MITI's list of Emerging Technologies, etc. Most of these lists have many common themes and, not surprisingly, include most topics that were studied by the JTEC teams.

Table 3 lists and compares the JTEC studies with both the National and DOD critical technologies lists. The JTEC studies listed in italics indicate that only part of the JTEC study is relevant to that technology. The number after the title lists the year a report was published; one asterisk indicates a report is in preparation but not yet available and two asterisks indicate that a study is planned but not yet started.

It is clear that JTEC's sponsoring agencies have been emphasizing technologies related to information services, although a fair amount of work has been done in the materials area, manufacturing, and space technology. However, no studies have yet been done on pharmaceutical, medical, and environmental technologies.

One JTEC study was unlike the others in that it looked at a Japanese initiative in basic research. The program is called ERATO, which stands for Exploratory Research for Advanced Technology Program. It is a novel program, and although it has been in existence for some time now, it actually was not reviewed by the Japanese until our JTEC team came to Japan. Its successes or failures are hard to judge, since the main objective is to develop a cadre of people in certain areas, to do good work, and then to disperse the scientists and engineers throughout the Japanese technical community.

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[3] Cecil H. Uyehara, "Appraising Japanese Science and Technology," in *Japan's Economic Challenge*, Joint Economic Committee, Congress of the United States, 101st Congress, 2nd Session, October 1990, pp. 289–307.

[4] Office of Science and Technology Policy, "National Critical Technologies List," (Washington, D.C.: Executive Office of the President, 1991).

[5] Department of Defense, "Critical Technologies Plan" (Washington, D.C., 1991).

TABLE 3 JTEC Studies Compared with National and Department of Defense Critical Technologies

National Critical Technologies	JTEC Studies	DOD Critical Technologies
MATERIALS		
Synthesis and processing	Advanced Materials (1986) Superconductors (1989) Membrane Separation (1992)**	Superconductors
Electronic and photonic materials	Opto-and Microelectronics (1985) Superconductors (1989) *ERATO* (1988)	Semiconductor materials and integrated circuits
Ceramics	Advanced Materials (1986)	
Composites	Advanced Composites (1991)	Composite materials
High-performance metals and alloys		
MANUFACTURING		
Flexible computer-integrated manufacturing	Computer-Integrated Manufacturing and Computer-Assisted Design (CIM and CAD) for the Semiconductor Industry (1988) *Space Robotics* (1991)	Machine intelligence and robotics
Intelligent processing equipment	Mechatronics (1985) Machine Intelligence (1992)**	
Micro-and nanofabrication	Nanostructures (1992)**	
Systems management technologies	*Nuclear Power* (1990) *Construction* (1991) Materials Handling (1992) **	
INFORMATION AND COMMUNICATIONS		
Software	Computer Science (1984) Advanced Computing (1987, 1990) *Machine Translation* (1991)* *Database Systems* (1991)* Machine Intelligence (1992)**	Software producibility

National Critical Technologies	JTEC Studies	DOD Critical Technologies
Micro-and optoelectronics	Opto-and Microelectronics (1985)	Integrated circuits and materials (devices)
	Telecommunications (1986)	
	ERATO (1988)	Photonics
	X-Ray Lithography (1991)*	
High-performance computing and networking	Advanced Computing (1990)	Parallel computer architecture
High-definition imaging and displays	High Definition Systems (1991)	
	Displays (1992)**	
Sensors and signal processing	Advanced Sensors (1989)	Data fusion
		Passive sensors
		Signal processing
		Sensitive radars
Data storage and peripherals	Advanced Computing (1987, 1990)	
	Database Systems (1991)	
Computer simulation and modeling	*CIM and CAD* (1988)	Simulation and modeling
	Advanced Computing (1990)	Computational fluid dynamics
	Space Propulsion (1990)	
BIOTECHNOLOGY AND LIFE SCIENCES		
Applied molecular biology	Biotechnology (1985)	Biotechnology materials and processes
	ERATO (1988)	
	Bioprocess Engineering (1991)	
Medical technology		
AERONAUTICS AND SURFACE TRANSPORTATION		
Aeronautics	Advanced Composites (1991)	Air-breathing propulsion
	Space Propulsion (1990)	
	Displays (1992)**	
Surface transport technologies	*Materials Handling* (1992)**	
	Superconductivity (1989)	

National Critical Technologies	JTEC Studies Technologies	DOD Critical
ENERGY AND ENVIRONMENT		
Energy technologies	Nuclear Power (1990) Nuclear Instrumentation and Controls (Europe) (1991)*	
Pollution minimization, remediation, and waste management		
NO NATIONAL OR DOD CRITICAL TECHNOLOGIES COUNTERPARTS		
	Telecommunications (1986) Space Robotics (1991) Machine Translation (1991)*	

NOTE: * denotes study in progress;
** denotes study planned; italic type designates partial overlap.
SOURCE: George Gamota.

The work falls into two major categories: physical and biological. Nearly half of the projects have been in biotechnology, which indicates the importance that the Japanese attach to this area for the future.

JAPANESE STRENGTHS AND WEAKNESSES

It is difficult to make categorical statements about the strengths and weaknesses of a nation in a technology without using many caveats. Unfortunately, the more caveats cited, the less persuasive the argument.

Nevertheless, it is necessary to synthesize data and to present it in such a form that policymakers and the nontechnical community can easily understand the importance of the findings and their implications. To this end, comparisons between Japanese and American technology are presented in a graphic way in Table 4.

The table shows only a few highlights. For a more in-depth description, the reports themselves should be consulted. As one peruses this chart, one can see common threads. Products are the single most important Japanese strength. This is true, not only in electronic components, but in many other areas. Another interesting factor is that in many cases, Japanese R&D is competitive with the United States. Japan is weak in many basic research areas, but even there, government and industry are taking steps to overcome this deficiency.

TABLE 4 Japanese Strengths and Weaknesses

	Japanese Position		
Technology	Strong	Competitive	Weak
MATERIALS			
Carbon-fiber	Products	R&D	Basic research
Carbon-carbon composites			R&D, manufacturing
High-strength polymers		R&D, products	Basic research
Electronic (Si and GaAs)	Products	R&D	II–VI materials
Biopolymers			All processes (but gaining)
Superconductors	Processing	R&D	Theory
ELECTRONICS AND INFORMATION TECHNOLOGIES			
Microelectronics	Memory chips	Logic chips	Microprocessors
Lithography	Optical and X-ray		
Displays	Products		
Machine translation	Products	R&D	European languages
Data bases		Image and multimedia	Products
Memory storage	Optical	Magnetic	
Computers	Laptop components	Supercomputers, hardware	Workstations, PCs
Software	Factories	Software engineering	R&D, products
Sensors	Charge-couple devices	Products	Research
Telecommunications	Component and fiber optics	Mobile	Networks
ENERGY AND PROPULSION			
Nuclear power	Instrumentation and controls	Construction R&D	Computer code
Rocket propulsion		Liquid rocket	Scramjet technology turbopumps

	Japanese Position		
Technology	Strong	Competitive	Weak
MANUFACTURING			
Flexible manufacturing systems	Products		
Software			Human-machine interface (but gaining)
Manipulators	Products	R&D	
Precision engineering	Products	R&D	
Robotics	Products	Systems	
Computer-integrated manufacturing	R&D, products		
Computer-assisted design		Applications	New concepts and tools

SOURCE: Compiled by George Gamota from JTEC reports.

METHODOLOGY OF ASSESSMENTS

I have focused on JTEC here and made only passing references to other studies. Clearly, since I had a major role in getting JTEC started, I believe it is one of the best programs around. For the amount of money being invested, it is probably the best we can do, but it pales in comparison with the effort foreigners make in assessing U.S. technology. After all, MITI's original charter was to look for and transfer foreign technology. It has resources that are several orders of magnitude larger than those expended by the United States on JTEC and other, similar efforts. MITI's studies are much more detailed, top-down arranged, and followed closely on a timely basis.[6] A weakness of JTEC is its inability to easily review technologies repetitively due to its funding mechanisms. There are many technologies that the JTEC staff would like to follow up on, but where funds from interested sponsors are not forthcoming. Additionally, a JTEC report is really the first step. It should be followed by a more intense, focused study, possibly including a visit to Japanese laboratories. There are many mechanisms in place for this to happen, but, unfortunately, there are no systematic processes for this to occur.

Europe also takes technology assessments seriously and pays attention to them.[7] DOD's Critical Technologies Plan is, in my opinion, the closest parallel to some of the better foreign assessments. The plan tries to paint roadmaps for weapon systems and makes references to dual-use technologies. Its positive virtues are that it is updated annually and utilizes various sources of information. Its limitations are that it is not in-depth enough and many of its references are not listed. Input is drawn entirely from DOD's personnel, including the intelligence community.

LESSONS LEARNED

Japan's technology investments have produced an amazing number of success stories. That is not to say that Japan is always successful. The Japanese tend to be conservative, but they also are willing to take chances if there is a consensus that the investment will pay off in the long run. Although sometimes gaining consensus is time consuming, once the Japanese decide to do something, they move rapidly, and without further discussion.

One of the most interesting aspects of Japanese technology is that technology is of signal importance to the government. However, less than 20 percent of the funds available for R&D in Japan comes from the public sector, as compared to 50 percent in the United States. Assisting the prime minister in setting the course for science and technology policy is a small group of senior people, within the government and outside. The top group includes the president of the Science Council of Japan.

In judging from anecdotal evidence and from my own experience, it appears that it is common for Japanese manufacturing companies to be headed by engineers; by contrast, in the United States many companies are headed by MBAs and lawyers with little or no technical expertise. As a result, input from industry to government tends to be much more "business" and less "technology" oriented in the United States than in Japan. Chief executive officers (CEOs) who personally do not understand technology tend to either underestimate or overestimate its importance, in contrast to those who deal with it on a firsthand basis. In areas where risk taking and timing are important, it is very difficult to ask people to risk much money on a project that they technically do not understand. It is this lack of being fully willing to make a commitment in science and technology, other than

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[6] Ministry of International Trade and Industry, *Trends and Future Tasks in Industrial Technology* (Tokyo: MITI, 1988).

[7] See Commission of the European Communities, *EC Research Funding: A Guide for Applicants* (Brussels: Commission of the European Communities, 1990).

to basic research, that has shaped U.S. government science and technology industrial policy for many years.

Japanese research and development activities remain rock steady: total spending continues to rise healthily, and spending patterns show little change from an overview perspective. However, on closer examination, it is clear that those responsible for Japan's science and technology policies are actively wrestling with the conflicting requirements of budget pressures and increasing calls for Japan to contribute more to the world's stock of basic scientific knowledge.

Internationalization of Japanese R&D will not be an easy process either for the Japanese managers, who must alter their way of doing things, or for the foreigners, who are concerned with Japan's competitive challenge and are suspicious of ulterior Japanese motives. Nevertheless, the process has begun and could have a profound global impact in the long run.

Pork-barrel projects are just as popular in Japan as they are in the United States, with one major difference. In the United States over half of the R&D dollars come from the taxpayers, while in Japan, it is less than 20 percent. Most of the R&D funds are provided by a technically-oriented industry and are focused in areas they think have the highest payoff.

Much has been written about technology transferred from the United States to Japan. This pattern continues today as Japan taps into U.S. basic science. To the dismay and chagrin of many scientists, this process not only continues but has been accelerating. For example, leading Japanese computer and electronics companies are opening laboratories to do basic research in the United States, luring some of the most creative American computer scientists to work for them.

Some researchers and economists see this as a direct threat in the one area of computer science—software—where Americans still have a distinct advantage. These critics say the Japanese effort could reduce the quality of research at the universities and damage the competitive position of the United States in a critical field that frequently produces the striking innovations that translate into tomorrow's products, but others say the competition for the relatively few stars in the field of theoretical computer science is natural and could be beneficial for science. Reactions to this vary from those who say the Japanese are wasting their money because they do not know what to buy, to those like Massachusetts Institute of Technology computer industry analyst Dr. Charles Fergusen who say that "it's closer to the end of the world."

The NEC Corporation has opened a research laboratory in Princeton, New Jersey. Matsushita is going to open one next year near San Francisco. Canon is starting one in Stanford, California. Mitsubishi is talking about starting one near the Massachusetts Institute of Technology in Cambridge. American scientists say they have also received recruitment inquiries from administrators at two other Japanese companies Fujitsu and Ricoh, which have told some computer scientists that they are considering starting laboratories in this country.

As a footnote, I should note that this is not exclusively a Japanese idea. American companies have had R&D laboratories in Japan for a few years now and have hired Japanese researchers to do much of the work. As of 1989, there were 42 U.S. companies operating laboratories in Japan, the largest being IBM. A few others include DuPont, Eastman Kodak, Honeywell, W.R. Grace, and Xerox.

There are many examples where the Japanese have followed through on American ideas and have done extremely well with them. They are not reluctant to acknowledge where their success is based on someone else's work and are proud to honor foreigners responsible. For example, in 1990, Dr. George Heilmeier, who is now CEO of Bellcore and previously was a senior executive with Texas Instruments, was honored for his pioneering work on liquid crystals, the backbone of flat panel displays. Dr. Heilmeier as a young researcher at RCA Laboratories showed that images can be formed by applying electric fields to a liquid crystal, an organic material—first used in digital watches. Unlike the RCA Laboratories, which supported the early work but did not recognize the full potential for over 20 years, the Japanese continued to research and develop liquid crystals, and now plan to make them the centerstone for a multibillion dollar business.

In contrast to the many examples of technology going to Japan, over the last 10 years a new trend started to emerge—Japanese technology coming to the United States. This comes in two forms: joint partnerships, where both the U.S. and the Japanese partners share in bringing technology, manufacturing, and marketing to the table; and less common, but potentially even more important, direct licensing agreements, whereby a U.S. firm obtains rights to use or manufacture Japanese-developed technology. This latter form is, of course, the one most commonly used by Japanese companies in the past in acquiring U.S. technology.

There are several explanations for this trend. First, even many in the United States have now come to realize that Japanese efforts in applied research, and certainly in development, are on par with or are ahead of those in the United States, and that partnerships and/or direct licensing makes business sense. One need only look at who is patenting in the United States. In 1979, the three top companies being awarded patents in the United States were General Electric, Westinghouse, and IBM. In 1989, the three top companies were Hitachi, Toshiba, and Canon.

Second, there is a fair amount of political pressure being put on Japan by the U.S. Congress and, to a lesser extent, the administration, to share its technology.

Third, as Japan becomes a global economic power and Japanese firms expand their operations beyond Japan, firms must open facilities located in their markets; otherwise the products will continue to be perceived as foreign and will be subject to possible constraints—nationalistic, political, economic, and social. A good example is that Honda's automobile assembly facility in Ohio is now shipping some cars to Japan. Since cars are driven on the left in Japan, the Ohio facility had to be designed early on to handle the changes, so this was not a last minute action attributable to slow car sales in the United States. The interesting question is, are these Hondas being exported to Japan American or Japanese cars?

JOINT VENTURES

While there is a thin line between some partnerships and licensing agreements, I want to concentrate here on partnerships and to discuss licensing next. Partnerships have become an important way of doing business in recent years. They often take the form of two companies, one from the United States and one from Japan, sitting down and pooling forces to set up a venture. Each brings something to the table and, if successful, each makes a profit. It can be a win-win (or lose-lose) situation.

Here are a few examples. One of the prominent joint ventures, and still probably one of the biggest, is the Toyota-General Motors New United Motors project in Fremont, California. Both companies profited from the deal. General Motors learned the Japanese way of building cars and used the experience to launch its own Saturn line, while Toyota learned how to do business in the United States with an American labor force.

A more common type of joint venture is represented by Sumitomo forging an alliance with a promising young company, Southwest Technologies, Inc., in the Midwest. For the American company, it represents an easier entry into Japan. As part of the deal, Sumitomo will attempt to obtain all necessary Japanese approval of Southwest Technology's products. The Kansas City, Missouri, company has developed a glycerin and water gel for hot and cold use in physical therapy and as a wound dressing.[8]

In another typical example, Monsanto and Tokyo-based Toray Industries have established Montor Performance Plastics Company, to produce and sell nylon resin products primarily to Japanese automotive manufacturers in the United States. The venture, which is based in Detroit, will also sell products to U.S. auto manufacturers in cooperation with Monsanto.[9]

Another recent example unites IBM and Omron Corporation from Kyoto. IBM teamed up with Omron to develop a range of user-specific automation

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[8] See *The Japan Times*, February 17, 1990.
[9] *Chemical and Engineering News*, February 1990.

equipment. The agreement will enable the two firms to consolidate their product lines in a joint push into Japan's financial, distribution, and public sector markets. Omron has been establishing itself in the Japanese markets for automatic teller machines, point-of-sale equipment, and automated ticket gate systems. Cooperation is expected in systems installation and employee education.

LICENSING-JAPANESE TECHNOLOGY TRANSFER TO THE UNITED STATES

Partly because of the debt they feel, and partly because they would like to start assuming the role of teachers, the Japanese have started to play a role in sharing their technology. It also makes good business sense. There is some evidence from industrial activities that indicates a shift in thinking. The evidence is anecdotal, and the level of effort and its impact are as yet unclear, but a change is definitely occurring and could be a signal for future events.

Specific examples are hard to come by, except from newspapers and some company brochures. Often, it is not the kind of news companies publicize. The number of actual exports of technology licenses from Japan to the United States is tracked by the Statistics Bureau of the Management and Coordination Agency of Japan. It cites 398 licenses being exported to the United States in 1989. This is double the number in 1984, although it is important to remember that the United States is still exporting much more technology to Japan than vice versa.

Some agreements have been reported. A few examples can be cited. Mitsubishi and AT&T announced that they have signed an agreement to design and manufacture static random-access memory (SRAM) chips. Under the agreement, Mitsubishi will supply SRAM chip design and manufacturing technology to AT&T, which, in turn, will gain manufacturing and sales rights to market Mitsubishi's SRAM products worldwide. Mitsubishi is willing to license its technology in return for banking on AT&T's enormous distribution network in the United States and Europe, thus improving its worldwide market share in semiconductors.[10]

While there certainly is a movement in Japan to start sharing technology, many more activities focus on joint ventures for cooperative R&D. A call for joint development of the next generation of computers, the so-called Sixth Generation or Real World Computing project, is an example of possible future trends. With some fanfare at an international computer conference held in Tokyo on March 14, 1991, the Japanese government invited leading computer companies in the United States and Europe, along with

[10] *The Japan Times*, February 17, 1990.

top research universities, to participate with them in a 10-year project to develop advanced computers for the next century. MITI is leading the effort. Proprietary questions, as well as political and trade questions, will have to be addressed. Work is at the beginning stages, but Japan and the United States are exploring collaboration in optical computing.

Much is made of Japanese industrial representatives visiting U.S. campuses. What is not said is that this enhances the ability of U.S. faculty to have access to Japanese companies. A number of the JTEC panelists from universities have established strong ties with Japanese researchers, many of whom have studied here in the United States. Those former students are extremely helpful, not only in the JTEC visits, but also for other information exchange purposes. To be sure, company secrets are preserved, but precompetitive work is generally made fully available. The enthusiasm of the visits is such that, to my surprise, even some competitive work is discussed. On several occasions, however, the panel received letters after the visit asking that certain technology not be included in the report due to its proprietary nature.

The chairman of the JTEC study on Computer-Integrated Manufacturing and Computer-Aided Design in the Semiconductor Industry, William Holton of the Semiconductor Research Corporation, told me after his trip to Japan that he was surprised by the openness of the Japanese industrial labs, which in some cases were more forthcoming than the American companies he works for.

One of the strong common threads in the JTEC reports is the belief that if current trends continue, Japan will dominate more and more high technology markets. This is not to say that it will dominate all high technology industry, but we can be sure that if there is a large market, the Japanese will be in it and will be trying to perform state-of-the-art work to ensure that their products are the best. High quality and state-of-the-art work are Japanese trademarks.

Unlike the United States, Japan has an economic strategy tied to end-use products involving long-term investments in R&D. Not all investments pay off, but enough do to make it a very attractive industrial policy. The Japanese do not "dabble" in research in the hope that something will come out that has a commercial payoff. Their research is tied to specific problems that are related to products, and those products are leveraged in markets that they control or intend to control.

Luckily for the United States, not all Japanese investments have met with success. One example that JTEC teams have tracked for seven years is software. In spite of large investments by the Japanese in this area, including the creation of "software factories," they still trail the United States. To be sure, they have not given up, but recently have acknowledged the difficulty in the next step of advanced computing.

In the West, particularly in the United States, being associated with a technological failure is usually detrimental to one's career. In Japan, decisions are made by consensus, and risks are taken by all concerned. If a program fails to meet its technological objective, most of the people associated with the undertaking share the disappointment, but seldom is an individual's career path threatened, since it was a group decision. Moreover, the Japanese try to learn from the failures and document the findings, as if the results were positive. As a result, there is much less duplication of effort in Japan than in the United States.

Even though basic research is weak in Japan, in many technologies it is improving steadily. In some areas, for example, superconductivity and electronic materials, Japanese basic research is on par with the United States. Many other examples can be found in the JTEC reports.

Closely associated with the improvement in basic research is the strengthening of university research in Japan and the coupling of such research to industry. Japanese university research has traditionally played a secondary role in the country's research enterprise. Initial JTEC teams were so disappointed with what they observed that for a long while, few teams even wanted to visit universities, other than to pay social calls. Today that is changing. Recent JTEC teams have noted that not only has university research steadily improved, but even more significantly, Japanese industry is paying more attention to what is going on at universities. The Japanese government has recognized the existence of barriers between university and industrial research, and has not only started to remove them, but has instituted a number of programs to encourage cooperative research.

Really unfettered research is seldom seen in Japan. Much of the basic research ultimately is tied to some need and, if successful, has an immediate pipeline to a commercial process or product. Except for the ERATO projects, most basic research is directed by a well-thought-out roadmap to possible applications. In addition to ERATO, it appears that the Japanese have chosen superconductivity as the flagship of their basic research efforts and are competing successfully on a worldwide basis. Their focus is on high-temperature superconductor materials.

Manufacturing products is the single most important element of Japanese strength. In contrast to the Japanese approach to managing basic research efforts, one finds that U.S. research is often oriented to solving ever more difficult problems, whereas the Japanese concentrate on solving incremental problems closely tied to product development. The United States tries for the "giant leaps," while Japan consistently notches ahead.

As I mentioned earlier, in some critical areas, such as artificial intelligence, software, and a few others, the Japanese have decided to fund basic research in the United States. Some of the work is being done at prestigious U.S. universities, while some is being done at Japanese-owned R&D

centers at major U.S. locations. The work there is first class, and most of the results are published in U.S. journals. However, the Japanese carefully look at the results for possible applications to their product lines.

When JTEC was started, one of the preconceptions was that it would be extremely difficult to get useful information from the Japanese since "they are secretive" and because the language barrier provided them with an easy excuse for not telling visiting Americans about the important things going on. We found that the opposite is true. Like most researchers, the Japanese are eager to share their work and in most cases go far beyond what would be expected from comparable visits to U.S. companies. To be sure, good advance work is necessary to ensure visits to the right places. One has to prepare himself/herself to ask the right questions, but rarely has a JTEC team not been given access. The hardest visits to arrange were to U.S. subsidiaries in Japan. They operated more like U.S. companies in America. Language is really not a problem; since we had at least one Japanese-speaking member of the JTEC technical team, more information was exchanged and it enhanced the results.

JTEC is viewed very positively in Japan since the Japanese have been engaged in programs similar to JTEC on a much larger scale. They believe in the importance of gathering information and are very good at it. As we saw earlier in Table 1, the trade balance with the United States in information gathering is roughly three to one; that is, Japan buys three times more information from the United States than the United States buys from Japan. In terms of people exchange, the numbers are even more skewed. For every ten Japanese scientists or engineers visiting the United States for an extended time, only one American goes to Japan. It is so badly out of balance that the Japanese government even funds Americans to spend time in Japanese laboratories.

Although written by over 120 scientists and engineers from all walks of life, the JTEC studies convey an overall impression of Japanese research and development that is scarcely subject to misinterpretation: Japan is currently engaged in a systematic effort to achieve parity with, or superiority over, the United States in virtually every technology that is of current or potential economic significance. It is not unlike that of U.S. determination in the 1950s and 1960s to be best in defense. In order to achieve this goal, the U.S. government supported such technologies as computers, microelectronics, radar, and space. The mechanisms by which Japan has pursued its strategy, and the extent to which it is succeeding, should be of great interest to policymakers in the United States and in the rest of the world. The Japanese make no secret of their objectives or methods. Quite to the contrary, they offer the rest of the world a possible blueprint for the pursuit of economic prosperity through thoughtful, long-range investment in science and technology.

What Can We Learn from Technology Assessment?

SHIGETAKA SEKI

EXPECTATIONS OF TECHNOLOGY ASSESSMENT?[1]

Recently, technology assessment has been receiving more attention than ever before due to the growing perception of technology as something critically important to both national security and industrial competitiveness.

Although the tension between East and West has been reduced dramatically, the Gulf War reminded us of the importance of maintaining military technical superiority as a deterrent to potential military buildup by Third World countries.

Within the nonmilitary economic sphere, competitiveness is a matter of national concern, since employment, the balance of payments in international trade, and national income are influenced by the health of a country's industries. Technology is seen as playing a key role in the development and improvement of products and of manufacturing processes. Therefore, it is natural for citizens to want to know whether their country possesses sufficient technological capability to make its industries competitive in the world.

In light of national security, the health of the nonmilitary industrial sector is also a matter of concern. Most of the important high technology from the nonmilitary sector is applicable in the defense sector, and the

[1] The term "technology assessment" is usually used to define the evaluation of the impacts, the influences, or the consequences of a particular technology on economic or industrial activities, on societies, on the environment, or on human health. In this paper, however, I use the term as an effort to understand national technological capabilities via an international comparative study.

dependence of the latter on the former for such things as the supply of components and manufacturing technologies has increased.

It is natural that governments are concerned about whether their nation's vital industries can compete with the industries of other nations. Further, should such problems exist, governments may try to resolve them by taking measures such as reallocating R&D resources, improving the infrastructure, modifying regulatory settings or tax systems, and creating trade incentives. Technology assessment is, therefore, an important policy tool.

ILLUSIONS ASSOCIATED WITH TECHNOLOGY ASSESSMENT

The essential question at hand is to what extent technology assessment can respond to the concerns presented above. Unfortunately, there are several problems associated with technology assessment that often cause it to be misinterpreted.

First, technology is not necessarily the dominant factor deciding an industry's competitiveness. Too often, people tend to focus on the performance of a product when the technological level is assessed. However, performance is only one of the elements that influence the competitiveness of the product. Price, design, and services at the time of and after the sale of the product are also important factors in competitiveness, although they are not necessarily directly associated with technological sophistication. For components, compatibility is another important factor that determines competitiveness. In the world of personal computers and video recorders, the availability of a variety of commercial software has also been important for success (e.g., in the predominance of VHS over beta). Easy-to-understand operation manuals or textbooks (and available training courses) increase the competitiveness of the products such as word processors and machine tools. Moreover, fluctuation in the exchange rate can easily offset efforts to cut costs or to increase productivity by the accumulation of incremental technological improvements.

Naturally, it is difficult to assess the future technological competence of a product by evaluating the current technological potential or research and development.

Second, how should we define a nation's technological capacity? Increasingly, independent enterprises have globalized their production and research activities, making their substantive nationality obscure. Therefore, the competitiveness of a nation is not automatically equal to that of its domestically owned enterprises. In addition, it has become impossible for an enterprise to depend solely upon original technology. Firms develop products or processes by taking advantage of self-developed technology as well as licensed and purchased technology from other domestic and foreign sources.

Another consideration is that sometimes firms pursue strategic partnerships with their international competitors. For example, many such partnerships have been formed in the automobile and semiconductor industries. In the automobile industry, there are numerous items and stages in the process of designing and manufacturing a car. Therefore, there are many opportunities for a company to cooperate with its competitors—in certain fields and stages of research and development, for example, or perhaps to have another company supply a certain component. Yet, when the end product is sent to compete in the marketplace, it will face products from those very same companies. In the semiconductor industry, technological progress is extremely rapid and requires a large amount of investment. The diversification of related technologies is also rapid. There are tens of thousands of variations of semiconductors, each incorporating various technologies. Also, there often exist several alternative technologies that can be used to produce certain types of products. For example, there are two fundamentally different approaches to create a circuit on a wafer, the stuck method and the trench method. Firms are not always certain which alternative will survive into the next generation of manufacturing, or whether completely new methods will supplant the existing ones. It is impossible for a firm to pursue independently all the variations of such technologies. Therefore, companies try to hedge the risk inherent in the development of new products through strategic partnerships with their competitors. When firms become deeply interdependent internationally in terms of technology, it is difficult to define "national technological capabilities."

TECHNICAL PROBLEMS ASSOCIATED WITH TECHNOLOGY ASSESSMENT

Usually technology assessment attempts to compare the performance of a product made by different countries (or firms), and/or the level of manufacturing or processing technologies of a product. When future technical capability is investigated, the research and development potential of a product as well as the quality and availability of an infrastructure (or any environmental conditions) for its development are also subject to examination. However, there are technical limitations in this assessment that we must keep in mind.

Assessment of Product Performance

When the highest functional performance of a product is in question, as is likely in the case of the evaluation of weapon systems, the performance of the high-end products is usually compared. In this situation, making a comparison is usually not very difficult since the results are likely to be measured numerically. However, should an evaluation that takes economic efficiencies into consideration be conducted, the results might not be so straightforward. It is likely, for example, that a marginal improvement in the performance would require a substantially larger amount of resources. Therefore, taking into account a limitation of resources—both financial and human—the technological superiority of a certain product may simply reflect the priority of resource allocation. Even in the assessment of the performance of weapons, cost must be a substantial consideration. Needless to say, however, cost consciousness is probably more important for nonmilitary products.

There is also a technical question in evaluating those products that have a wide variation of types. Should products of the high end (the highest performance) be compared, or should we compare the medium (or the largest-volume) products? How should products that are differentiated when firms (or countries) demarcate the market be treated? Articulation of the objectives of the assessment is critical when there exists great product variation. Automobiles are one such area. The origin of variation in automobile production comes from the differences in the concept of designing a car. Fundamental design (or the philosophy of the design) depends on the targeted users. There is a variety of elements that cause product differentiation. Further, there are cases whereby different technological options exist, and since each has advantages and disadvantages, it cannot be said that one is superior to another. For example, in controlling the supply of fuel and combustion in the cylinder of an engine, both electronic and mechanical means are applicable. Depending on the circumstances, it does not automatically follow that an electronic device is technologically superior to a mechanical device.

Assessment of Production Processes

Many factors influence the performance of a product, and there are no universal criteria to weigh all factors together.

First of all, an assessment will differ depending upon whether the intent is to produce high-performance products regardless of the cost or to manufacture products in the most cost-efficient manner.

Secondly, there are many nontechnological factors that significantly influence both the performance and the productivity of the manufacturing process. For example, the motivation of workers is a very important factor even in a highly automated semiconductor factory equipped with the newest instruments and facilities. The yield in such a factory can be greatly influenced by dust (in particular, dust contaminated by sodium ions) created when people enter the clean room. Many firms have created teams to tackle the problem of reducing dust. Not all of the members of such teams are engineers or experts in certain specialties. Teams used average workers to test how dust might be generated by motion, such as walking, speaking, clapping hands, and breathing. Some teams tested the measure of sweat that might leak from workers' clothes. Through practical research, the teams discovered important know-how. Workers are now required, for example, to change gloves twice a day to suppress the emission of small fiber pieces, and must take a bath and change their underwear before entering the clean room to eliminate contamination by sodium ions. With all of these efforts, there are bound to be variations in the productivity performance of the workers in a semiconductor plant. In other words, there are variations in worker performance that cannot be ensured only through a manual or work policy.

Efforts to improve productivity like those mentioned above are nothing but traditional approaches to troubleshooting. Such troubleshooting is necessary even when the dead copy of a factory (or a production line) in operation is replicated. There is no magic that makes a difference, rather an effort of engineering-focused minds. Within technology assessment, there is a difficulty in measuring the importance of such aspects; indicators (i.e., quantitative measures that could show technological advantage) providing means to evaluate the entire technological value are elusive.

The third point is that newness or technological sophistication of instruments and facilities used in production does not automatically guarantee an advantage in performance; nor does it ensure high productivity in the manufacturing process. In many cases, the human factor plays a significant role. For example, one very competitive machine tool manufacturer uses manually controlled mother machines that have been in operation for decades.

Finally, how should we assess the technological capability of a production process when numerous suppliers, both domestic and foreign, supply very important materials and components? One may argue that key technology materials and components should be assessed within the evaluation of the whole production processes. However the question of what the key technologies truly are arises. Regardless of the technological sophistication of certain materials or components, they may not be attractive to manufacturers if the supply is not stable. On the other hand, when the supply of such components is stable, manufacturers will not be concerned even if those sophisticated materials and components are provided only by a limited number of suppliers. Some materials and components may constitute a part that cannot be replaced by others. Needless to say, it is difficult to assess the impact of this phenomenon when the production process for a product is scattered all over the world. The criteria and the measure of the technological assessment may vary significantly, depending on the emphasis of the conductor of the assessment.

Research and Development Potential

Research and development potential is frequently discussed as a measure to foretell the future technological capability of an industry or country.

However, the assessment of such potential is no less complicated than the assessment of the production process discussed above.

First, two fundamentally different approaches exist: namely, evaluation of originality and creativity, and evaluation of a product's application and improvement potential. Which approach is taken depends upon the analyst's judgment and how he or she weighs these factors.

Second, the planning and management of research and development projects are influenced by the strategy of the R&D designers, and whether they choose to emphasize short-term results or to plan for expansion into future possibilities. Firms that seek short-term tangible results may show higher levels of productivity in research and development. However, their long-term success may not necessarily be at the same level.

Third, some companies may place priority on product development, and others on process development. In addition, in certain cases, new product development and new process development must be synchronized; both must be given equal emphasis. This is evident, for example, in the production of miniaturized appliances, such as personal cassette recorders.

Fourth, there are different stages in research and development: basic, applied, and development. Among these, basic research has the character of being "common property" for all nations; therefore, a country's strength in the level of basic research does not necessarily mean that the country will be strong in more advanced R&D stages. However, basic research might be expected to provide a major contribution to the other stages through lending a supply of well-trained and educated experts.

Fifth, similar to the situation in evaluating the production process, many enterprises from different technological areas are involved in the R&D process, particularly in the field of manufactured goods. Domestic firms are not the only participant enterprises.

Finally, many international enterprises perform research and development all over the world. Should the ability of research institutes owned by foreign firms in a country, for example, be counted as part of that country's national R&D capability? It should be counted if the conductor of the assessment is interested in finding out whether or not a nation as a geographical region provides favorable conditions for research and development.

In conclusion, there is no a priori criterion for evaluating research and development potentials. Besides, it should not be forgotten that competition in the market is an important catalyst for research and development. A survey conducted by the Ministry of International Trade and Industry (MITI) three years ago revealed that companies considered competition to be the biggest incentive for R&D (over 70 percent), while limitations in the numbers of researchers and the amount of investment were major disincentives (45 and 35 percent, respectively). In contrast, abundance of researchers and adequate available financial resources worked as an incentive for R&D only modestly (18 and 27 percent, respectively).

Infrastructure

There are numerous conditions that influence production as well as R&D activities; for example, the industrial setting, competition among firms, the existence of capable suppliers, regulations, the quality and quantity of the labor force, transportation, electricity and water supply, and the information network. Which factors are selected and what criteria are applied to the evaluation depend on the concerns of the conductors of the assessment.

Problems Associated with Methodology

In addition to the complexity of the technology as discussed above, there are limitations on the process of assessment in terms of methodology. A popular way of collecting data is to categorize technological fields in order to send questionnaires to the experts in selected fields, then to process the responses statistically. For an objective evaluation, it is desirable to compare quantifiable indicators. However, in such questionnaires the field experts are commonly asked to provide their personal evaluations (e.g., by choosing one of three alternatives: superior, even, or inferior) of the technological level or potential of specific products or key technologies. There are two reasons for this method. One reason is that it is not easy to find appropriate objective indicators. In addition, many indicators may not be available to the assessment team because of corporate secrecy. Also there are so many factors which influence technological capability that it is hard to find a way to examine those factors and make a total evaluation. Therefore, the conductor of the technology assessment might conclude that it is better to leave the fundamental evaluation to experts in the field. One problem with such an approach is the fact that the information the experts have could be fairly limited. Particularly, this would be a problem in the event that the products or production process to be assessed involved many different technologies (or industries). In such a situation, the answers of the field experts are significantly influenced by the widely shared views spread by mass media. Whether such views actually reflect reality may not be sufficiently challenged.

Another frequently used method is to make an evaluation based on selected key technologies. However, as discussed previously in this paper, there are no a priori objective criteria to select key technologies. A standard method is to ask the experts to list what they consider to be critical technologies.

A survey conducted for a MITI white paper on industrial technology three years ago followed this approach in assessing 40 technological and product fields. Through interviews with experts, technologies from different industrial fields were selected as key technologies (see Figure 1). It is significant that various technologies might have played key roles in determining the outcome; also the fact that the importance of a specific technology might have changed from time to time should have been considered.

Technology / Product	Material			R&D Application, Production												Common		
				Design, Application					High-Performance Production							System		
	High-Performance Material R&D	Processing	Purification	Materials and Components	Application	Design	Testing	Control	High Performance	Large scale	High speed	Automation	Production Management	Construction	Maintenance	Systems	Communication	Software
1. High-tensile strength steel				●		●			●									
2. Amorphous alloys				●	●				●									
3. Superconductors (at temperature of liquid helium)				●	●				●				○			○		
4. Fine ceramics				●	●	●							●			●		
5. New glass					●						●							
6. Macromolecule separation films				●		●			●				●			○		
7. Engineering plastics				●	●				●									
8. Composite materials				●	●	●			●		●		●					
9. Optical fiber	●	●		●							●	●		●		●	●	
10. Semiconductor lasers					●	●			●			●				○		
11. CCD		●			●	●			●							○		○
12. Semiconductor memory elements		●				●			●			●	○			●		○
13. Microcomputers	○					●			●			●	○			●		●
14. Bore screws					●	●			●									
15. Servo motors					●	●						●	○			●		
16. Hydraulic pressure regulating valves					●	●		●	●			●				○		
17. Optical-magnetic disks					●					●						○		
18. 1/2-inch home VCRs				●	●	●			●							●		
19. Computers	○			●	●	●			●				●			●	●	●
20. Databases																●		●
21. CAD/CAM													○			●		●
22. Copiers					●	●			●							●	●	○
23. D-PBXs				●					●									
24. Assembly robots				●					●				○			●		○
25. Laser machining equipment					●		●	●	●				●					
26. Laser printers	○				●	●						●						●
27. Accelerators					●			●	●									●
28. Spectrum analyzers				●		●	●									●		
29. Aircraft engines	●								●									
30. MRI				●	●	●	●											
31. Artificial kidneys	●								●			●				○		
32. Bioproducts using animal cells			○		●				●	●		●	○			○		○
33. Bioproducts in botanical field	○				●	●			●									
34. Bioproducts using microbes			○		●	●			●	●						○		
35. Light water reactors	○				●	●							●		●	●		●
36. Solar energy	○			●	●				●	●								
37. Satellite launch rockets						●							●			●		
38. Communications satellites																		
39. Seagoing structures					●	●							●	●	●	●		
40. Super-high-rise buildings	●				●	●							●	●	●	●		

Figure 1 Locus of key technologies for selected products. Note: CCD = charge coupled device; CAD/CAM = computer-assisted design/computer-assisted manufacturing; D-PBX = digital private branch exchange; MRI = magnetic resonance imaging.

Source: Survey conducted by Agency of Industrial Science and Technology, 1988. Note: ○ indicates that respondents mentioned general areas of technology; ● indicates that respondents mentioned specific technologies.

The case of the optical fiber field is one good example. The development of the optical fiber was initiated by glass manufacturers. Then, a cable-making company developed the technology for coating the glass fiber, which successfully enforced its mechanical properties. Next came a new laser technology that allowed wavelengths to be transmitted through this fiber for long-distance communication. This development was followed by the discovery of the vapor-phase axial deposition and the modified chemical vapor deposition methods, which enabled mass production of the fiber. A lesson from this case is that different types of element technology played key roles at different times to advance a whole technology. Another matter of note is that enterprises in different technological fields entered into the development process. It is not always clear which industrial sector will enter into the process of development of a new technology. Besides, as previously mentioned, it is often not certain which technological alternatives will survive into the future.

Indeed, the uncertainty of future technological development adds to the difficulty of technology assessment. There are usually several options that can be used to attain the targeted functional performance or productivity. For example, chemical methods as well as biological methods can be used in producing chemical compounds; depending on the specific compounds, different methods are adopted. In a survey by the Department of Defense (the *Critical Technologies Plan*), optic technology is named as a critically important technology. Several performance targets are listed, and an evaluation of the technological levels of various countries is performed. However, some experts point out that the performance of certain targeted devices may be achieved by optical or nonoptical means; it is likely that many electronic devices will be used complementarily to an optical system.

Finally, careful consideration should be paid to which specific technologies or products are chosen as subjects of an assessment. To assess national technological capabilities, usually a group of selected high technologies is examined. However, high technology products account for only one part of the total industrial output. Traditional industries such as steel, petrochemical products, and automobiles hold larger shares of the total output than computers and aerospace-related products. Yet, one may argue that high technologies stimulate economic activities as a whole and are valid to measure in this respect. It is true that there are many high technology elements adopted in the production process of traditional industrial products. However, high technology will not bring a large benefit to a nation if its application is not pursued aggressively in those industries that have a large output. In other words, assessment of the technological capability of the industries that produce high technology commodities is not sufficient to evaluate the technological capability or competitiveness of all of a nation's industries.

OUTLINE OF THE TECHNOLOGY ASSESSMENT PROJECT CONDUCTED BY MITI FOR THE WHITE PAPER ON INDUSTRIAL TECHNOLOGY (1988)

The Ministry of International Trade and Industry conducted a technology assessment project covering 40 industrial products and technologies for the preparation of a white paper (published in 1988) on industrial technology. The purpose of this assessment was to identify Japan's strengths and weaknesses in specific technologies, at specific stages of research and development. It was supposed to be a trial that would illustrate complex realities of the method by assessing several different elements of technologies.

Technological levels were investigated in three areas, namely, products, key technologies, and research and development potential (Figure 2). The

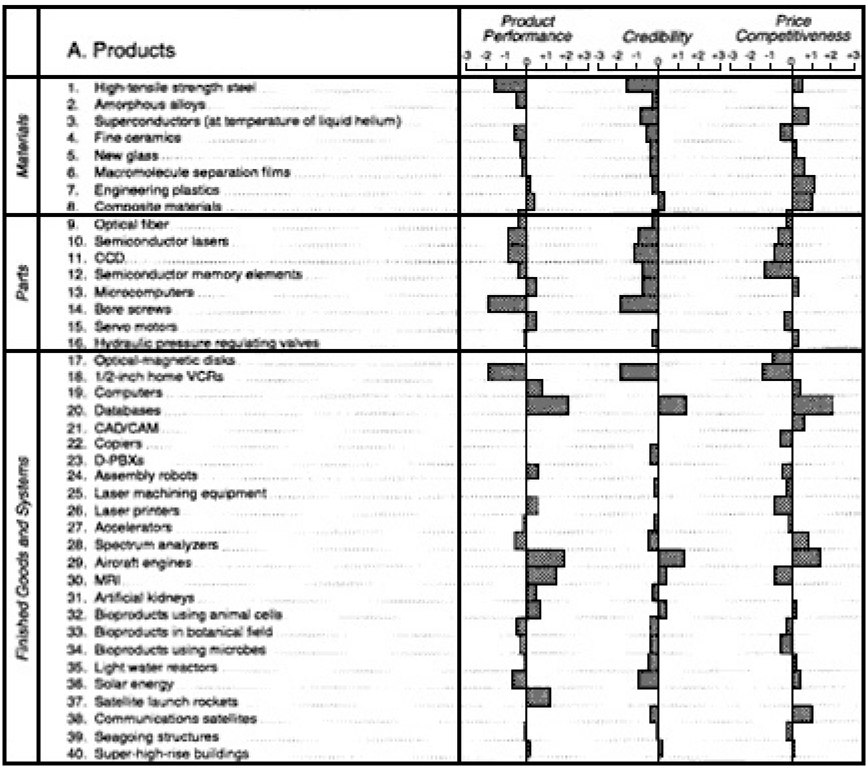
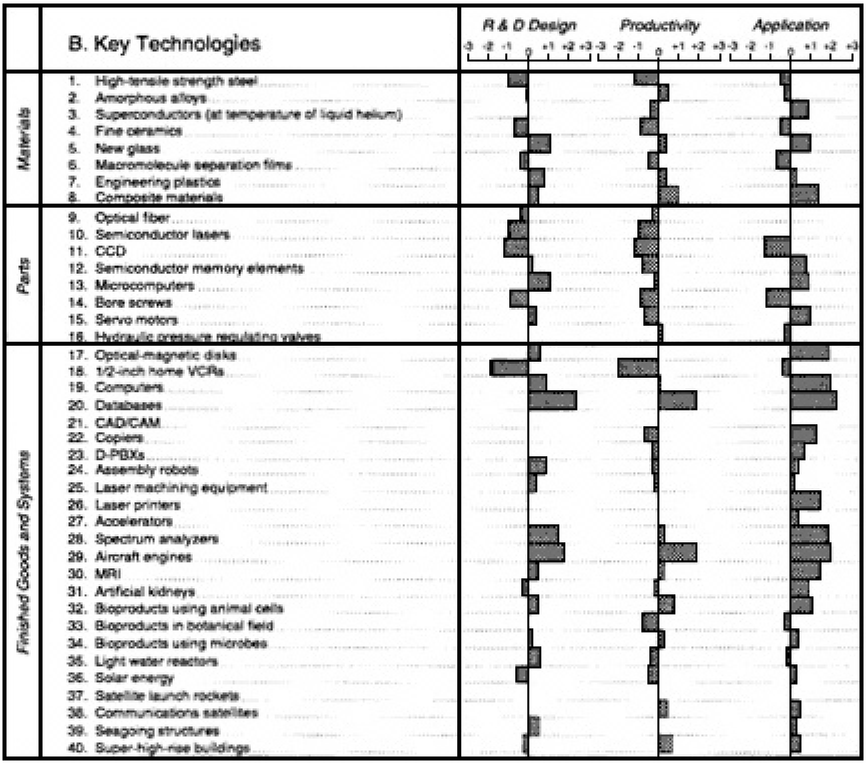
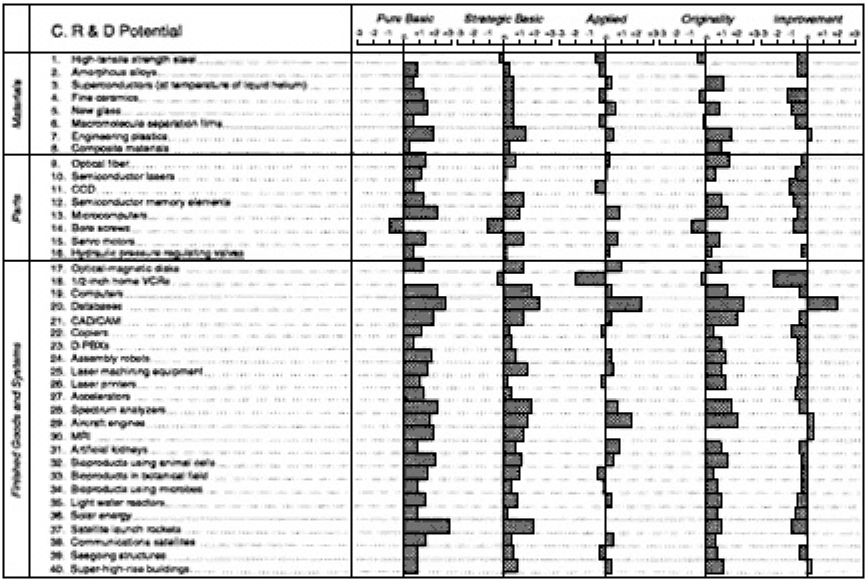


Figure 2 Technological levels of the United States and Japan—products (current U.S. levels compared to Japanese levels). Note: CCD = charge coupled device; CAD/CAM = computer-assisted design/computer-assisted manufacturing; D-PBX = digital private branch exchange; MRI = magnetic resonance imaging. Source: Survey conducted by Agency of Industrial Science and Technology, 1988.



technological level of products was assessed in three aspects: product performance, reliability, and price competitiveness. Similarly, key technologies were chosen with three criteria in mind: the capability of research, development and design, productivity and the ability of application. The research and development potential was evaluated from five different standpoints: the abilities in basic research, in strategic basic research, and in applied research; originality; and capability for improvement.

The survey produced several interesting findings. First, Japan had an advantage over the United States in reliability of many of the products. In product performance and in price competitiveness, Japan had an advantage for some products but was a disadvantage regarding others; the overall performance of Japan was equal to that of the United States in parts, finished goods, and systems. In materials, the United States had an advantage in price competitiveness in six out of eight areas of technology. The United States led in many of the key technology areas, particularly in applications. The United States showed strength in pure basic research, strategic basic research, and the originality of R&D potential. Regarding the improvement factor, Japan's performance exceeded that of the United States. Unfortu nately, the details of the survey were not presented in the white paper. Instead, an aggregated performance was shown in the paper, in which the overall technological level and the R&D potential of key technologies were evaluated as a simple average of the performance in different aspects of products and R&D. Vital information regarding the realities of the various assessments was lost in the process of aggregation.



OBJECTIVES OF THE ONGOING SURVEY FOR THE PREPARATION OF THE NEXT WHITE PAPER ON INDUSTRIAL TECHNOLOGY

As discussed in this paper, the realities of technological assessment are very complicated and a simple comparison of overall technological performance does not do the issue justice—and, therefore, can be misleading. This was an important lesson learned by MITI through the last survey. The natural question, then, is what can we learn from technology assessment, and how should we go about doing so?

The experience of the previous survey provided a hint. Technology assessment can explain the reality of technology: that is, what technology is, and how it is generated and used. In other words, technology assessment can be used as a tool to identify how scientific and technological activities of different disciplines interact, how one industry is dependent on others in terms of technology, to what extent the globalization of scientific and tech nological activities prevails, how innovation takes place, and what the environmental factors that stimulate innovation and diffusion of technology are. Indeed, these are the objectives of the ongoing survey (on technology assessment) that is being conducted by MITI for the preparation of the next white paper on industrial technology, set to be published next spring.

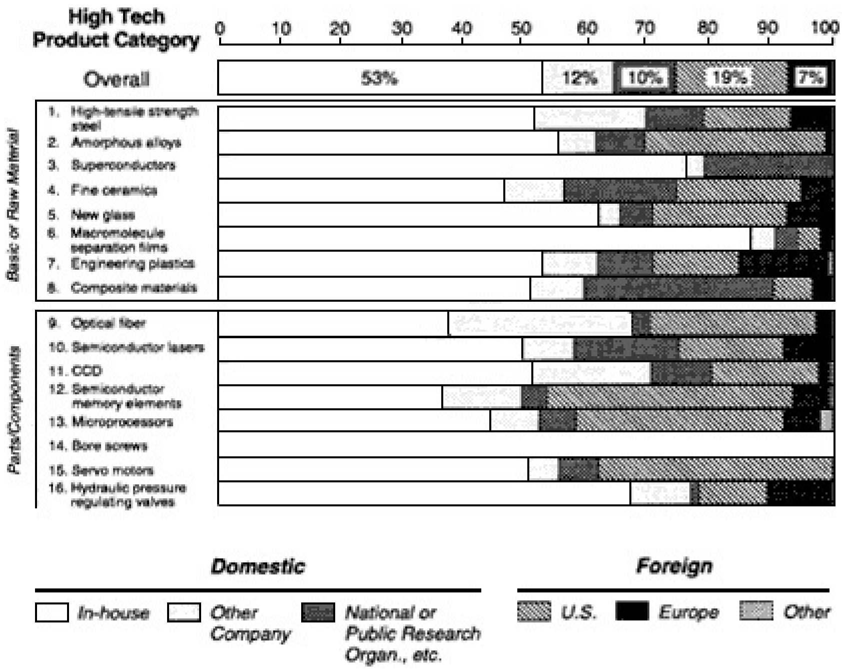
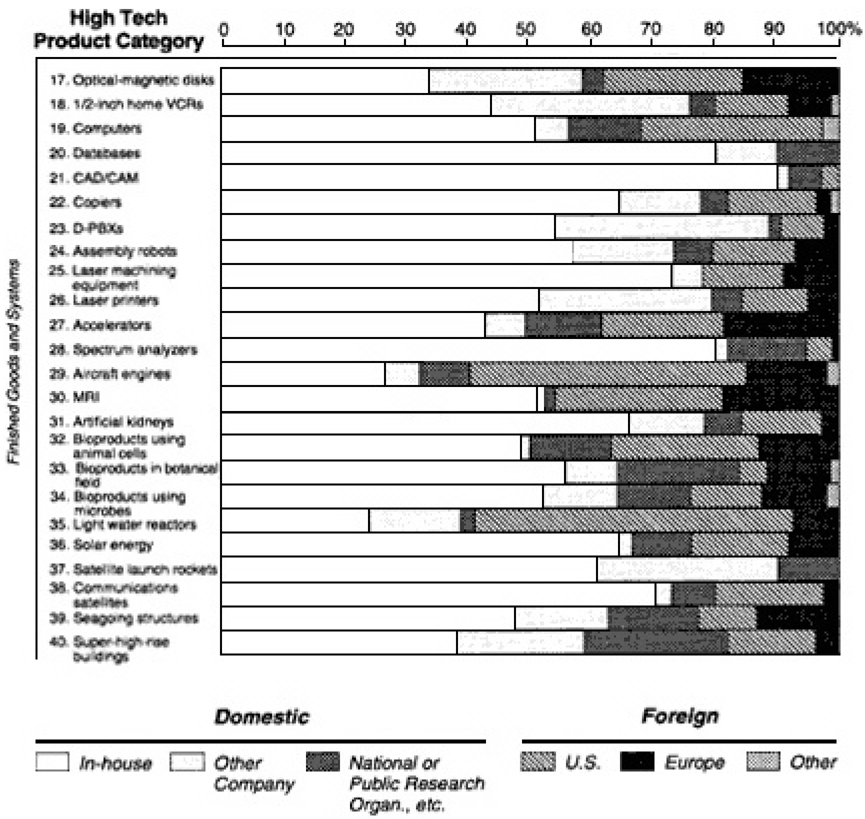


Figure 3 Dependence on domestic/foreign patents and know-how for high-technology products. Note: The dependency factor is a measure derived by first classifying patents and know-how (that are actually employed in designing, producing, or using a product) by the "inventor," then by quantifying the degree to which the respective "inventors" contributed to the said design, production, or use. In making the quantification, overall consideration is given to the quantitative and qualitative contributions of the patents and know-how. CCD = charge coupled device; CAD/CAM = computer-assisted design/computer-assisted manufacturing; D-PBX = digital private branch exchange; MRI = magnetic resonance imaging.
Source: Survey conducted by Agency of Industrial Science and Technology.

In the survey, some 20 industrial products will be examined. They will be chosen not for their technological sophistication, but by the size of the portion of the market that they hold as an objective criterion. Therefore, many of them will not be high technology products; for example, offset printing and the automobile industry will be highlighted.

The survey intends to evaluate the products (industries) from four as pects: product performance, performance of the production processes, research and development potential, and the environment for R&D. In each of the areas, as many indicators as possible will be collected in the hope of an objective analysis. The set of such indicators will be different for different products. Any important technology used in the production of the products, regardless of whether it is new or old, will be cited for consideration in the evaluation. The survey is expected to explain the evolution of certain technologies, as well as the conditions and environments that facilitated or inhibited the development of these technologies.



Also efforts will be made to identify these technologies as original, licensed domestically, or imported. The reason for such efforts is not so much that MITI wants to compare Japan's original technologies against foreign technologies, but because of the intent to illustrate the interdependence between firms and industries on a global level.

In this respect, the previous survey also tried to identify the extent of interdependence (see Figure 3). It showed considerable interdependence in all of the 40 products surveyed. However, we should be careful in reading the results. The results were based on the aggregated data of how experts saw the situation in their own technological fields, including consideration of both qualitative and quantitative aspects. It does not necessarily follow that some specific technology, though a small share, made an unimportant contribution to production. The matter of concern is that however small the contribution may have been in percentage terms, the product would not be produced without the technology. The new ongoing survey puts focus on this interdependence.

It is essential that policymakers understand the conditions and environments for innovation and diffusion of technologies, the situation of deepened interaction between scientific and technological activities of different disciplines, and the globalization of these activities. The reason for this is that a suitable policy is one that would provide appropriate conditions and environments for technological development. This was recommended in the Organization for Economic Cooperation and Development (OECD) Ministerial Council last June as a result of three years of discussion under a special program entitled the "Technology and Economy Program." In addition, the globalization of scientific and technological activities has illuminated the issue of bringing domestic policies to a point of international harmonization. For this purpose, the OECD will discuss whether there is a need to develop additional "rules of the game" in the future.

POLICY IMPLICATIONS

Technology assessment will provide important information to policymakers on how technology evolves and is disseminated. In other words, it will tell them details about the conditions and environments that stimulate innovation and the diffusion of technology. Therefore, policymakers should be better equipped to develop policies that would create favorable conditions for innovation and the diffusion of technology.

Another important message that can be transmitted through technology assessment is the reality of deepening interdependence in industrial activities beyond natural boundaries. The question that should be raised is not to what extent should we depend on foreign sources for the supply of critical commodities and technologies, but rather how can we sustain stable relations between countries so that we can maximize the benefits of interdependence?

Accessing Japanese Technology: Experiences of a U.S.-Based Company

JIM F. MARTIN

INTRODUCTION

Rockwell International's sales in Japan include semiconductors for modems and GPS (global positioning system) applications, newspaper printing presses, factory automation equipment, truck and automotive components, and other mostly commercial equipment. Annual sales there through our Japanese divisions are around $150 million; we have approximately $130 million more in direct exports to Japan from the United States and Europe. We employ more than 400 people in Japan, largely for sales and service; these numbers are growing slowly. Some of our industrial relationships there are brand new, and some (in aerospace) go back to the mid-1950s.

The purpose of this paper is to briefly describe the experience of a U.S.-based company in accessing Japanese technology: who's doing good work, how to assess it, and how to get access to it. Most of the paper is based on my personal experience in Japan, from 1986 to 1991, directing an office to support technology assessment and access for Rockwell's divisions in Japan and in the United States. This office has a broad technology charter, assisting nearly all of Rockwell's businesses: electronics, aerospace, automotive components, factory automation, and printing presses. Most often, the office works from a list of technologies that have been identified as strategically valuable, and it reports data and results directly to the requester. In addition, these and other events in Japan's technology infrastructure are compiled in a monthly newsletter distributed internally.

During this period, we found that engineering groups within our company were able to accurately evaluate technology and, when it became desirable, were able to gain access to Japanese technology with about the same proprietary and legal constraints as they would face in the United States. We encountered significant limitations and differences relative to the United States, arising from the language and culture (both personal and business), but with a significant investment in personnel in Japan, we found that these challenges can be managed and to some extent leveraged for a competitive business advantage. Judging from our discussions with other Western companies in Japan, our experience is not unique.

OVERALL CHARACTERIZATION OF JAPANESE TECHNOLOGY

In the popular comparisons of Japanese and U.S. technology, university and national laboratory research groups are seen to be significantly behind, and small high tech start-ups are said to be virtually nonexistent. By contrast, according to this popular image, large Japanese corporate technology labs are ahead in many technologies, and in general it is very difficult for a U.S. corporation to gain access to them or work with them in a meaningful way.

This popular characterization is generally accurate, but there are many opportunities for collaboration with technical groups in industry, government, and academia. Most university and national laboratory research in Japan is indeed well behind that in the United States, primarily because of the huge disparity in government funding for such research. Despite this and other major constraints, a few leading professors and institute directors have managed to set up significant, highly creative laboratories, outstanding even by U.S. standards. These exceptional labs are easily discovered, and are relatively approachable and interested in making connections with U.S. companies. These connections can bear fruit in research collaborations and in assisting recruiting of excellent technical people, a critical factor in Japan's tight market for technical personnel.

High tech start-ups, at least ones that are not dedicated to a large company, are far more rare in Japan because of the business environment, but they are increasing. Start-ups with relatively advanced technologies are hard to find, but when contacted are often very interested in working with U.S. companies. A good example is Nippon LSI Card, which we discovered in a JETRO (Japan External Trade Organization) tour of the United States in 1987: they make non-contact semiconductor memory, which we designed into our truck electronics product line.

Gaining entry to medium and large corporations in Japan is difficult because of the fierce, competitive business climate. However, the more advanced labs publish in journals, their research engineers attend conferences in the United States, and their public relations departments are very active. Therefore, it is frequently a straightforward task to determine which companies are the leaders in a specific technical area. Furthermore, if a Japanese company is a supplier or customer, it is probably approachable concerning joint development in the product line in which a mutual interest exists. Because Japanese companies are so aggressive about market share, linking up with a U.S. company may represent a new way to get an edge in the market, especially if the company name is not known in the United States.

The defense and aerospace sectors in Japan spend far less than the United States on R&D, relying for the most part on spin off from their commercial businesses. However, in certain technical areas, they have developed technology of genuine interest or have put laboratories in place that will help them gain significant markets in the future. Although cooperation between governments has been thrown into some confusion in recent years by the FSX fighter project, the U.S. space station, and other projects, there are many areas of potential cooperation between companies. Examples include composite materials, infrared imaging, microwaves, avionics, and automation.

LOCATION AND EVALUATION

Our first step in setting up the office for technology access in Tokyo was to recruit an experienced Japanese Ph.D. engineer to be my associate. Together with our customers in Rockwell's businesses, we developed the modus operandi, including three basic types of activity for the liaison office: tech window, obtaining requested data or samples, and supporting negotiations for exchange of information, licensing, or joint projects. We found several sources of information valuable, but the primary filter was frequently my associate or our colleagues in Rockwell's Japanese operations. As a result of their education and working experience in Japan, these employees already have a wealth of knowledge about companies, universities, and national labs that is invaluable.

To supplement this knowledge base, we found the following sources of information in Japan useful:

- suppliers' and customers' labs and engineering groups;
- trade journals, company journals, and conference proceedings;
- international conferences and Japanese conferences and exhibits;
- patent literature;
- standards groups and professional societies;
- ACCJ, AEA, AAIJ, and other business organizations*;

- American embassy;
- the Ministry of International Trade and Industry (MITI), including its international R&D collaborations;
- trading companies; and
- consultants and research companies

In addition, certain sources of information in the United States on Japanese technology also proved to be quite helpful. Among the most valuable are MCC's (Microelectronics and Computer Technology Corporation) monthly report for its members, and ScanC2C's (a U.S. company) Japan Technology data base, now available on DIALOG (a well-known on-line data base). MCC has a small staff that monitors technology developments worldwide and reviews the most interesting work; the quality of their reporting is excellent. ScanC2C provides abstracts (by mail or on-line) of articles in Japanese company technical journals.

The first on the above list, the laboratories and engineering groups of our business partners, are the most useful because they truly want to work with us. When genuine mutual interest is established, this type of access never fails to produce information or a project of value. Next, international conferences and Japanese conferences and exhibits are helpful because engineers and researchers from our company can quickly review a large number of companies (with some help from a technical interpreter). Furthermore, they often meet counterparts in Japanese companies or universities who are relatively frank about their work and the status of development of a technology. Properly followed up, these contacts can be maintained over several years and can serve as a crucial source of information.

Two other sources of information on the list deserve mention because they are perhaps not so obvious. The American embassy in Tokyo—especially the Department of Commerce, the office of the National Science Foundation, the Department of Defense, and the Department of State—can be enormously helpful in educating about current trends, providing pointers to the right companies, and providing introductions. MITI can also be very influential in enabling a foreign company to get the attention of a potential customer or supplier, and can cut through much of the confusion of working in Japan.

The activities in our liaison office included reviewing published articles in trade journals and elsewhere, discussions with companies or government agencies, and working with those in our own company to understand and answer their questions. At different times, we utilized several commercial data bases, including JICST, PATOLIS, COMLINE, ScanC2C, EGIS, DIG-IN, and others. Recently, it has become possible to get access to these and other Japanese technology data bases here in the United States through commercial gateways such as DIALOG.

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* (ACCJ: American Chamber of Commerce in Japan; AEA: American Electronics Association; AAIJ: American Aerospace Industry in Japan).

Initial evaluation is made by the technology liaison office, but the detailed evaluation is always carried out by a Rockwell engineering group. This evaluation frequently requires at least one technical visit by a Rockwell engineer. In really active cases, such as our investigation of flat panel displays, Rockwell engineers visited potential Japanese sources at least once every three months over a period of years.

Technical areas in which we are particularly impressed with Japanese industry include (but are not limited to) composite materials, synthetic diamond, superconductivity (high temperature and low temperature), semiconductor fabrication, electronic packaging, compound semiconductor devices including semiconductor lasers, electro-optical devices, flat panel displays, fuzzy logic, neural nets, factory automation, and machine tools. To accurately describe the relative status of Japanese technology in any of these areas requires reviewing the work in universities, industrial labs, and products that are on the market. In many of these areas, Japanese scientific development lags the United States, but commercialization is significantly more advanced. It is common to find situations where U.S. university or industrial laboratories, or high tech start-ups, are ahead of any effort in Japan, but only Japanese companies are really capable of economically producing related products in any volume.

Finally, there is the most serious issue of relative capability in manufacturing. A succinct description appears in the final report of the U.S. Department of Defense Technology Assessment Team on Japanese Manufacturing Technology: "...Japanese excellence in manufacturing as manifested in the rapid commercialization of new technologies, superior productivity and high quality is not due to access to better automation or manufacturing technology, but to a pervasive and deep belief in the strategic importance of manufacturing excellence, better exploitation of advanced process technologies, and to smarter management and organization."[1]

GETTING ACCESS

The overriding factor in discussion of a technology alliance with Japanese companies is what potential partners have to offer, beyond dollars. There is a strong sense that there must be mutual benefit, in which the other company's technologies, manufacturing, and marketing capability provide more leverage than they could discover elsewhere. Pure "technology for dollars" deals are not interesting to the Japanese, because they always look several years down the road, to how the arrangement will be useful to them in the long run. So deals can be made, but dollars alone are not enough.

[1] See U.S. Department of Defense, *Findings of the U.S. Department of Defense Technology Assessment Team on Japanese Manufacturing Technology* (Washington, D.C.: 1989).

Consequently, the most promising way to gain access to Japanese technology is through genuine cooperation with a Japanese company. The best candidates will be a supplier or customer. Cooperation takes many forms, but the primary feature is *dependence: the two companies involved agree to become dependent on each other*. This is a necessary part of what the Japanese refer to as "trust"; this trust must be established at several levels of management in order to produce mutual benefit.

In my opinion, this same feature, trust, exists in nearly all successful deals here in America. In fact, companies make headlines—the wrong kind—when it has been demonstrated that such trust has been violated.

Forms of cooperation between U.S. and Japanese companies include cooperative design projects, joint ventures (when they are well planned), participation in government-sponsored or private R&D collaborations, long-term exchanges of personnel, and other activities. To cooperate effectively, each company must contribute experienced personnel who are outstanding performers. Anything less on either side is a telltale sign of lack of commitment and usually leads to misunderstandings, stalled initiatives, and failure. In addition, each company must sign on for the long run, because the formidable barriers of different business practices, culture, and language require time and persistence to overcome.

In recent years, it has become easier to recruit experienced, high-quality Japanese technical people, through search firms, contacts at conferences, and relationships with universities. Senior people can frequently be recruited as they retire from MITI, from universities, or as they are pressured to retire from large Japanese companies while still in their fifties. These people bring with them the experience and contacts gained from their years in the Japanese industrial community, and can usually lead to others interested in working for an American company. The core group in one American company's research laboratory in Japan was recruited in just this manner.

As a final note, a real R&D laboratory in Japan is vastly superior to a liaison office for locating, evaluating, and accessing technology. Japanese researchers and engineers maintain friendships with colleagues from their educational years, they have intimate knowledge of the infrastructure in their technical area, they can communicate effectively with potential or established partners, and they are loyal employees. A number of American companies, including IBM, Eastman Kodak, Hewlett-Packard, and Texas Instruments, are taking advantage of this approach.

CONCERNS

Every year, there is stronger emphasis in Japanese industry on R&D funding—it is increasing overall, the focus on basic research and originality is sharper, and the mechanisms for improving industrial productivity in all sectors of design and production are being rapidly enhanced and refined. Japanese companies, motivated by competition in Japan and elsewhere in the world, are aggressively searching for methods to decrease their concept-to-market "productization" time to even lower levels in the future. Japanese industry, supported by the Japanese financial community and the government, invests readily in new equipment and in foreign (e.g., American) high tech start-up companies. Although there is recent anecdotal evidence that some of these investments are not yielding high returns, over the long term Japanese investment in U.S. high technology can be expected to grow steadily.

Despite the resulting increased technical strength in Japan, the technology flow between the United States and Japan continues to be very unbalanced, partly because of the great inequity between the two countries in easily available technical resources, and partly because Japanese companies are better (for financial and management reasons) at rapid commercialization of new ideas. Also, the vast majority of American firms believe that they cannot afford to make a similar level of investment because the way their financial performance is measured does not encourage long-term investments in capital or R&D. This is lending greater momentum to the closing of the technological gap between U.S. companies and their competitors in Japan and Europe.

The erosion of any company's leadership in technology lessens its opportunities to establish partnerships with other companies. So, as the Japanese become stronger technically, their need for American companies has lessened, and they turn away from the negotiating table because no useful benefits can be offered in return.

In addition, there are structural problems that inhibit the flow of technology from Japan to the United States. One of the most difficult to cope with is the strong tendency for Japanese companies to work only within their own *keiretsu*, or economic group. Within such groups, easy licensing terms are usually available, and special sacrifices are made to support other parts of the group. Foreign companies are usually not accepted into such groups unless they participate in a local joint venture, which often results in yielding control of their technology for that product line.

The U.S. government has played an instrumental role in pressuring the Japanese government to encourage changes in Japanese business practice in order to help American companies penetrate the Japanese market. This pressure has been necessary, in my opinion, but I believe that each company has a responsibility to be the best that it can be and to make the appropriate investments in order to sell its products. It is irresponsible to ask the U.S. government for help in entering a market if management is not willing to change its product in order to make it attractive to the prospective customer.

Compounding the technology flow problem, Americans' relative ability to commercialize new technology and manufacture high-quality products also appears to be deteriorating. Part of this change is natural, as other countries' industries become well-educated, well-financed, and experienced in developing high technology products. But the largest part of the cause lies with the complacency of American corporate and government management. Even those leaders who recognize that there is a problem are handicapped by organizations that are not yet convinced that there is a need for dramatic change.

RECOMMENDATIONS

The current situation in the United States is comprehensively described in *Made in America*, a book published by the MIT Press in 1989, by Michael Dertouzos, Richard Lester, and Robert Solow. They set forth five fundamental imperatives for the United States, which are well thought out and which are being studied by companies all over America. These imperatives do not represent a quick solution, but a way of life that U.S. businesses and government must practice if we are to arrest the current trend towards being second (or third) best in the world. Technology, manufacturing, and management practice are linked and cannot be separated without serious losses in quality and productivity.

In another report, *Emerging Technologies*, released in 1990 by the Technology Administration of the Department of Commerce, there is an excellent characterization of the status of 12 new technologies in the United States relative to Japan and Europe. In most of these areas, the report advises that the United States is losing ground to Japan. This report lists several areas called "opportunities for change" and recommends specific actions for government leadership, for government-industry cooperation, and for industrial leadership facilitated by the government.

In yet another 1990 report, "Scientific and Technological Relations Between the United States and Japan, Issues and Recommendations," by Dr. Frank Press and Dr. Martha Caldwell Harris, several excellent recommendations are made regarding investment in the United States and Japan and the need for cooperation in a number of areas.[2] These include Japanese investment in U.S. high tech start-ups and universities, treatment of multinational companies, and a detailed discussion of asymmetries in science and technology. One important element of the context is that Japanese industrial

R&D is always undertaken with an eye on the market—even long-term basic research projects.

In order to benefit from these and the dozens of other fine reports and books on these subjects that have appeared in recent years, both Americans and Japanese must carry out substantive and long-term changes in the operation of business and government. Neither country can any longer afford the luxury of looking at this problem as a simple "them versus us" competition: the two economies are so mutually interlocked that there is no turning back. The future economic strength of both countries is dependent upon developing methods of cooperation that improve industrial productivity and competitiveness in each country while making it possible to work together effectively. This discipline will not be easy, and the rewards will not appear in the short term, but by committing to making the needed changes, America will be able to remain technically competitive in the future, and Japanese industry will become a more welcome participant in the global economy.

[2] Frank Press, "Scientific and Technological Relations Between the United States and Japan: Issues and Recommendations," Commission on U.S.-Japan Relations for the Twenty-First Century, November 1990, with an attachment by Martha Harris, "Asymmetries and Potential Complementarities: Scientific and Technological Relations Between the United States and Japan."

Studies of Japanese Technology: An Effort with Diminishing Returns?

G. L. MILLER

THE DECLINE OF U.S. HIGH TECHNOLOGY MANUFACTURING

Literally dozens of books and hundreds of articles have appeared on the subject of the decline of American manufacturing and there is little doubt that this trend will continue unabated in the future. Many explanations have been given. These include such culprits as short-term financial thinking that underemphasizes capital investment, a generally undereducated work force, incompetent management, low regard in the society at large for manufacturing as an activity, top-down hierarchical organization that stifles creativity, declining enrollment in science and engineering as the best students pursue careers in Wall Street or the law, the high cost of capital, greed on the part of financial entrepreneurs, union problems, the lack of a well-defined work ethic, and essentially irrelevant business management school training. This list can be expanded and there is little doubt that it will be. However, there is a common theme that unites all of these complaints, namely, that they are clearly all to some extent true. To this long and growing list there has recently been added an interesting new contender, namely, "technology transfer," which will be discussed later.

Whatever the reasons, and whether or not the above list is complete, the facts of the matter are clear. The U.S. entertainment electronics industry has already been annihilated, both the automobile and semiconductor industries are reeling, and a graph prominently displayed on the wall at SEMATECH in Austin, Texas, predicts that the United States will lose its lead in computers around 1994.

The critical issue here is the design and manufacture of high technology products. Japan is now number three in the world in exports, and around 75 percent of these exports are high technology manufactured items. It is primarily this export activity that leads to Japan's tremendous positive balance of payments situation, around half of which arises from purchases by the United States. It is scarcely surprising that there exists increasing interest in the United States in studying all aspects of Japanese production.

THE RISE OF STUDIES OF JAPANESE TECHNOLOGY

While there is general agreement that the loss of U.S. high technology industries is undesirable for the nation, this opinion is not universal. It has even been proposed that on some sufficiently grand economic scale this does not matter since the U.S. consumer gets a better deal by buying the (better value) Japanese items. Whatever the merits of this interesting view, it is not one liable to find favor with the auto worker who has lost his job or with his representative in the U.S. Congress. For this and other reasons, it will not be the view taken here. Local and short-term and inwardly directed as the view may be, it seems reasonable to assume that the loss of high tech industry matters. The concerns with Japan vis-à-vis the United States in this arena therefore appear entirely justifiable, and consequently increasing Japanese studies *may* also be justifiable. Obviously the use of the word "may" in the previous sentence is somewhat pejorative. Haven't Japanese studies yielded valuable information in the past? Yes they certainly have, and a few representative examples will follow from previous JTEC (Japanese Technology Evaluation Center) studies [1] with which I have been personally involved. Such information spans many areas—technical, financial, organizational, and political—and some of it has proved quite surprising. For instance, it is well known that Japan employs a highly developed *industrial policy*. The complex interrelations that exist in connection with the sensor industry (see Figure 1), for example, are also quite representative of many other sectors. Of particular interest is the important role played by high technology *industrial trade organizations*, of which there are no fewer than 43 (see Table 1).

Among these organizations JEIDA (Japanese Electronic Industries Development Association) is one of the largest, and it plays an important role in many areas, not least in the sensor industry. For example, many of the (roughly 300) Japanese sensor manufacturers maintain permanent membership on one or more of the five JEIDA sensor subcommittees (see Figure 2). These committees have approximately 20 members each and meet around

[1] JTEC reports may be obtained from Loyola College in Maryland, 4501 North Charles St., Baltimore, MD 21210-2699.

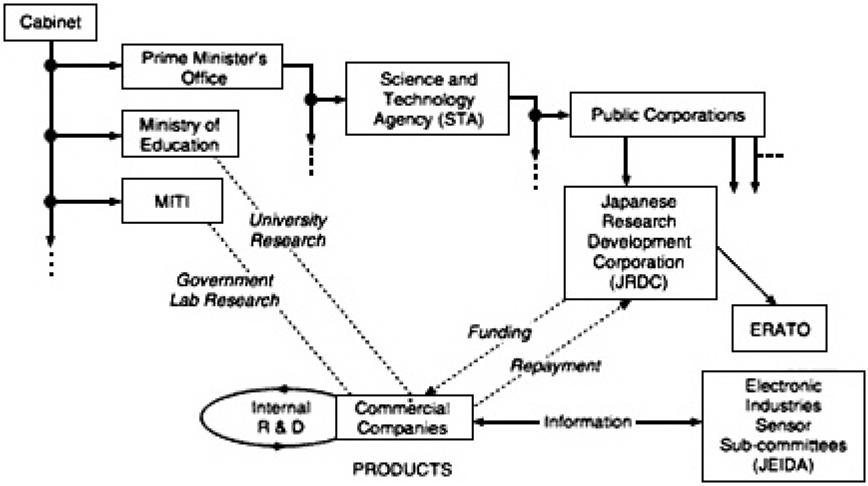

Figure 1 Mechanisms of funding and sensor development. Source: G.L. Miller, H. Guckel, E. Haller, T. Kanade, W. Ko, V. Radeka, "Advanced Sensors in Japan," JTECH, 1989.

TABLE 1 High Technology Japanese Industrial Trade Associations

Area	Activities	Numbers
Electronics	Communications, materials, information processing, components, optoelectronics	8
Mechatronics	Mechanical, robotics, automation, machine tools, high precision, automobiles	11
New materials	Petrochemical, electron devices, fine ceramics, chemical	4
Energy	Solar energy development, energy conservation, electric power, atomic power	6
Bio/medical technology	Biotechnology, fermentation, pharmaceuticals, medical equipment	4
Aviation/space/ocean	Ocean industries, aerospace	2
General technology	Research development, technical information, patent information, technology development	8
Total		43

SOURCE: G.L. Miller, H. Guckel, E. Haller, T. Kanade, W. Ko, V. Radeka, "Advanced Sensors in Japan," JTECH, 1989.

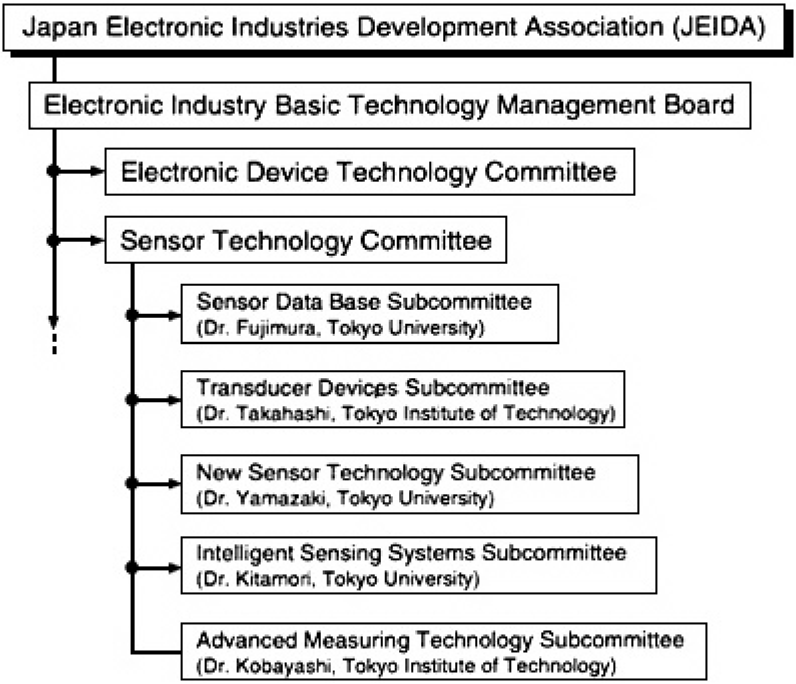

Figure 2 JEIDA sensor subcommittees. Source: G.L. Miller, H. Guckel, E. Haller, T. Kanade, W. Ko, V. Radeka, "Advanced Sensors in Japan," JTECH, 1989.

once per month. They exchange highly detailed technical information, "debrief" members returning from foreign technical trips, and produce an *extensive* "gray" literature, which is not routinely accessible to outsiders. This keeps industrial members constantly up-to-date with current sensor technology worldwide. There is no comparable U.S. activity.

It is also instructive to examine Japanese high technology companies and to compare them with their U.S. counterparts. Yokogawa Electric was chosen to be one of the companies studied in the 1988 JTEC Advanced Sensor investigation because it specializes in industrial measurement and control. It has approximately 6,500 employees, revenues of approximately $1.5 billion per year, and is number one in its field in Japan (see Figure 3). It also has links with Hewlett-Packard in the United States. Of particular interest is Yokogawa's stress on *inventiveness*. Each of the approximately 130 technical members of the corporate R&D organization is expected to submit three or more patentable ideas to the company patent department each year. The resulting flow of approximately 400 ideas leads to Yokogawa's filing of approximately 200 patent applications per year. This is an astonishingly high number by U.S. standards. By comparison, for example, AT&T Bell Laboratories with approximately 30,000 employees (including 1,000 in research) files approximately 400 patent applications per year.

Of course, Yokogawa is but one example of inventiveness on the part of Japanese companies. However, if one had to pick just one Japanese company on this score (particularly if normalized with respect to size and head count), the answer would have to be Sony. It has an extraordinary record of continuous innovation since its very inception in 1945. Furthermore, Sony has shown a remarkable propensity for parlaying what *starts* as advanced entertainment and consumer electronic technology "uphill" into

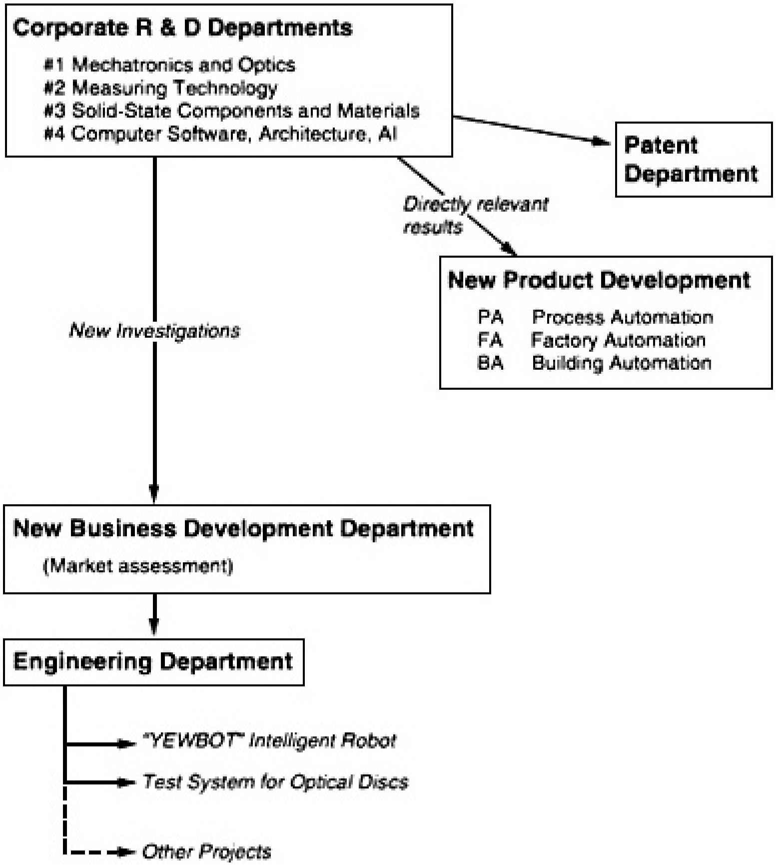

Figure 3 Yokogawa Electric R&D. Source: G.L. Miller, H. Guckel, E. Haller, T. Kanade, W. Ko, V. Radeka, "Advanced Sensors in Japan," JTECH, 1989.

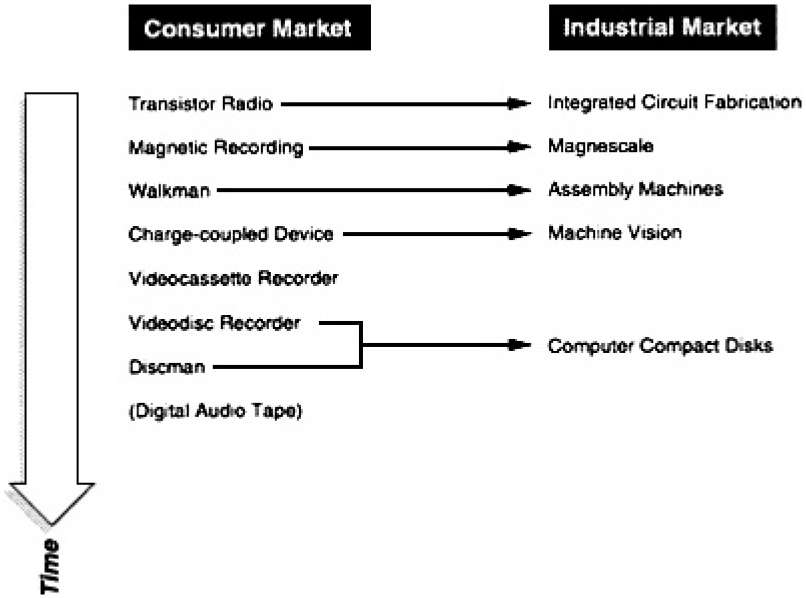

Figure 4 Sony products as a function of time. Source: G.L. Miller, H. Guckel, E. Haller, T. Kanade, W. Ko, V. Radeka, "Advanced Sensors in Japan," JTECH, 1989.

advanced manufacturing techniques and computer technology (see Figure 4). This can be viewed in some sense as the exact reverse of the U.S. claims of "spin-off" moving advanced, often military, research results towards consumer applications.

The preceding has been, by intent, a whirlwind overview of some high points regarding Japanese technological developments. Much more information on all of these topics, and many others, is available from the various JTEC reports[2] listed in Table 2. All of these studies represent a substantial effort on the part of specifically appointed panels, typically numbering around six people, who spend time in Japan and also research the literature extensively.

It is Table 2 that perhaps first justifies the use of the word "may" earlier in this section. Although it will be noted that the topics chosen are arguably important (a lot of thought certainly goes into their selection) it is apparent from the last column of Table 2 that only around 50 copies total

[2] Ibid.

are sold of each report per year. This is not exactly a stunningly impressive number.

TABLE 2 Total Sales to Date of JTEC Reports

Topic	Year	Total Sales
Biotechnology	1985	115
Computer science	1985	172
Mechatronics	1985	159
Optoelectronics and microelectronics	1985	159
Advanced materials	1985	248
Telecommunication technology	1986	158
Advanced sensors	1989	179
CIM and CAD for the semiconductor industry	1989	67
Exploratory research program for advanced technology (ERATO)	1989	98
Advanced computing	1990	50
High-temperature superconductivity	1990	53
Nuclear power	1990	16
Space and transatmospheric propulsion	1990	15
Space robotics	1991	9

NOTE: CIM = computing integrated manufacturing; CAD = computer-aided design.
SOURCE: Japan Technology Evaluation Center.

Of course, the JTEC organization points out that it actually produces around 200 copies of each report initially and these are carefully targeted to all the appropriate government agencies, Senate aides, and other relevant organizations in an early mailing, thereby reaching the "decision makers" inside the Washington beltway. Exactly. It is precisely *not* these people who produce the high technology products with which we are concerned. This is certainly not to denigrate the beltway inhabitants who are involved in these activities. All are without doubt highly competent. That is not the point. The point is effectiveness.

I have not myself followed up on all the sales of the JTEC reports, but this would be well worth somebody's while (perhaps in the National Research Council's Office of Japan Affairs). It would be my suspicion that a follow-up questionnaire to industry would indicate that the overall commercial impact of JTEC studies is in fact depressingly small.

Yet even this is not the main point to be made here. The real issue is the following. In almost all situations there are three major steps involved in solving a problem: first discovering what the facts of the matter *are* (which is often hard), then interpreting what the facts *mean* (which is harder), and finally deciding on a course of action (which is the most difficult phase of all). It is argued here that we are still in the first phase and that furthermore *we really already know more than enough of the facts of the matter*. Increasingly, to send study groups to Japan and to continue to examine every aspect of its productive system will yield continuously diminishing returns. If one is really concerned with improving the situation, the central issue is surely how to move to phase two and to try to understand what has already been learned and what it means for the United States. Of course it has already been pointed out that this is difficult, but perhaps something can be learned from history.

SOME TECHNOLOGICAL HISTORY

Consider first, for example, the case of the medieval swordmakers. By an extraordinary process of intuition, invention, trial and error, and continuous experimentation, they ultimately produced steels of unparalleled excellence. It is only within recent years (i.e., *centuries* later), that analytical techniques have been developed to the point that we can understand why these steels worked and how their production processes operated. To pick another example of importance to an amazingly large fraction of the world's population, consider the case of brewing and fermentation. Here again the actual mechanisms at work are fantastically complex, and by no means fully understood to this day, but that has not stopped the vintners from producing wines for *millennia*. And just in case it is thought that these are old examples and modern science and technology have now gone well beyond that point, consider the much more recent case of the telephone. This was based on just two inventions, namely, the carbon microphone and the electromagnetic earpiece. The latter was indeed understood from the outset, but the exact mode of operation of the carbon microphone was a mystery. Again, through an extensive process of experimentation, intuition, invention, and trial and error a *process* was devised that produced excellent microphones. This involved the use of a certain grade of anthracite coal from a certain mine, grinding to grits of a certain size, carefully heat treating in controlled gas ambients, packing the grits into a microphone in a certain way, and so on. In parallel with this *process* development, a department-sized research effort was mounted by the telephone company (at the old Bell Telephone Laboratory on West Street, New York City) to try to understand how the carbon microphone actually worked. This effort was finally abandoned as totally intractable after more than a decade of work.[3] All of these cases share a common thread. That thread is need, invention, intuition, extensive trial and error and the production of a stable fabrication procedure that does the job even though it may not be "understood" in any conventional scientific sense.

This process continues unabated to this day. The electronic revolution is now primarily based on silicon technology, the most complex microcircuits typically involving several hundred sequential process steps (of perhaps two dozen or so different but repeated types) to produce the finished device. It might well be thought that in this case at last we had finally reached a stage in which basic scientific understanding held sway, and that we therefore knew exactly what we were doing to any desired level of detail. This could hardly be further from the case.

To pick but two examples from the world of silicon microcircuitry, one of the first things that happens to a silicon slice, before any other processing is done to it, is that it is slurry-polished to a mirror finish. However to this day we really have no idea of *how* slurry polishing actually works. We can *control* the process superbly, however, producing finishes of no more than 100-angstrom surface roughness that are furthermore flat to fractions of microns over hundreds of square centimeters, and can do this completely automatically in machines that polish each wafer in only a few minutes. To cite just one more example one need go no further than the critical issue of the "flatband" voltage at the oxide-silicon interface in metal-oxide semiconductor (MOS) devices. Without control of this voltage, absolutely no MOS mass production of silicon microcircuitry would be possible. Here again, however, it turns out that detailed "understanding" of the science of this "interface state density" issue is still essentially beyond us. But that hasn't stopped us from carrying out thousands of processing experiments (worldwide over many years) *measuring* the resulting flatband voltage, and thereby slowly zeroing in on *conditions* that produce acceptable performance. That is precisely the same thing that the swordmakers did and the brewers did and the carbon microphone builders did. It is really no different. While some might view this as a humbling realization it needn't be. A more realistic evaluation might be that it simply extols the extraordinary power of human intuition and invention, *when coupled with a step-by-step process of incremental experimentation and test*.

It is at this point that someone will say, but what about the atomic bomb, or what about the laser? Certainly there exist extraordinary examples in which the process flowed in the "textbook" direction, i.e. starting from basic physical scientific understanding to produce truly *phenomenal* ultimate products and results. But that's not the point. Absolutely no one denies that this process exists and can point to tremendous successes. The more fundamental question to ask is for what *fraction* of the total time does this textbook process actually operate in a significant way.

In some sense, all of this can be seen as quite ironic. The clear message is that organized, or systematic, "incrementalism" ultimately wins hands

[3] We now understand in principle how it works, namely, via the tunnel effect, However, the *detailed* understanding of the extremely complicated surface physics involved would probably still be beyond us even now.

down in the technological race. But this was first clearly understood by an American, Thomas Edison. He is widely revered as an inventor. However, the case can be made that his extraordinary contribution really lay in a different direction, namely, in *organizing the incremental trial-and-error technological process*. He had terrific judgment in knowing just what was needed as the final goal, for example, an electric light. He then set his associates about the task of systematically testing materials for filaments. They tested no fewer than 6,000 and were ultimately "brilliantly" successful. Furthermore this is not an isolated example. However, this message seems to have gone astray in the United States in the last 80 or so years.

A VIEW OF TECHNOLOGICAL DEVELOPMENT

The preceding view of technological development, if taken to be true, leads to a number of conclusions. For example; that there is only a weak link between basic undirected fundamental research and new products, that scientific "spin-off" is largely a self-serving myth, and that Edisonian incrementalism wins in the technological race. In connection with the last point (while on the topic of stating the obvious that seems nevertheless to be invisible) one needs to start somewhere to get somewhere. For example, to *improve* something one needs to start by *making* something.

This means prototypes of actual physical things must be made before one can test them and improve them. The United States is not currently renowned for making prototypes, but the Japanese are. The Sony Corporation spends approximately 70 percent of its total R&D funding on building prototypes.[4] These things are then used, tested, and improved. By contrast there is a rapidly growing view in the United States that this whole process of prototype investigation can even be *circumvented* by computer simulation, allowing one to proceed directly from the concept to the manufactured product. Time will be the judge, but one can ask the question, which is more accurate, the simulation or the reality? It's certainly not clear how to simulate what the MOS device oxide growers have done for example. However, people will no doubt try, and a lot of National Science Foundation (NSF) money will be spent in the process. That's not all bad of course, but one needs to form a reasonable judgment of whether that will be technologically cost effective in the long run. And in addition it's a little difficult to do market trials with simulations of products; actual hardware prototypes are obviously vastly preferable.

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[4] Statement of Dr. Teruaki Aoki, Deputy Senior General Manager, Sony R&D Planning Group, to the JTEC Advanced Sensor Panel at Sony Headquarters Building in Tokyo, June 24, 1988.

Then there is always the "Sunday punch" theory, namely, that basic scientific research will somehow come up with a breakthrough "killer technology" that simply annihilates the competition. Well, that can and has happened. A classical example is, of course, the transistor. But, after all, *the transistor was invented over 40 years ago*. So, while eagerly awaiting the next such happy event, we need to notice the continuous and unrelenting advance of the juggernaut of Japanese technological incrementalism. In this case, in the eye of Achilles, the tortoise looks pretty ominous and maybe he really cannot overtake it. And that's not hard to understand; the tortoise keeps steadily marching ahead while Achilles spends his time running about in all directions. And in any case, even after the introduction of a "killer technology", no company or organization can expect to stay in the forefront for very long unless it in turn embarks on an organized program of continuous incremental improvement.

THE TECHNOLOGY TRANSFER ARGUMENT

An argument that has gained considerable popularity in the United States over the last decade or so goes something like this: "Since it is self-evident that technology rests in the last resort on basic scientific research, and since it is well known that the United States is preeminent in all the world in basic research, it follows that there must be something the matter with the way our basic research is transformed into technology." It was this conviction, for example, that led NSF to set up Engineering Research Centers at various universities a few years ago. The underlying thought was clearly that by coupling the group efforts of teams of research people at the universities to what were perceived to be problems of industry, technologically useful consequences would ensue. While it is true that the jury is still out in this connection, after some seven years of experience it is certainly not easy to point to many clear-cut successes of technology commercialization that can be credited to this Engineering Research Center approach.

Closely related to this mode of thought is the widespread belief in the United States in the efficacy of what is referred to as "scientific spin-off." This particular idea is most often invoked in connection with very large government research programs. It is epitomized in a newspaper headline that appeared a few years ago that read, "Europeans eager to share in the rich bonanza of technology that will flow from the SDI program." Again there is the belief that there exists a simple seamless link between research (even research on distant and completely unrelated topics) and a direct technological benefit. This same spin-off argument is also behind a variety of recent government initiatives that seek to make research results from federal and national laboratories more easily accessible to U.S. industry.

The clear implication is that the only thing that stands in the way of the "technological bonanza" is that industry is simply unaware of the scientific results. Again the technology transfer idea.

Many variants of the preceding scenarios exist, but enough has been said to indicate the nature of what is perceived to be the problem, namely, the *coupling* of fundamental research into useful technological products of broad benefit to society. However, it is argued here that this view is false. This follows not only from the history of such things as the Engineering Research Centers but also from the no more than marginal results of the heroic efforts of the national and federal labs to "transfer" their technology to the marketplace. Certainly there have been some individual successes, but it certainly cannot be argued that this approach is the key to anything very significant in view of the unabated U.S. economic slide. In any case, it is not at all clear that this approach is correct in view of such things as the actual history of major technologies as outlined above.

THE COMMUNICATION AND INFORMATION PROCESSING ARGUMENTS

Closely related to the technology transfer argument is the communication argument. This holds that what is needed in the United States is a huge, ultrahigh-speed computer communication network that will allow huge amounts of data to be transferred from everywhere to everywhere with blinding speed. This, it is held, will enormously increase U.S. competitiveness in every area, but particularly in the areas of research and high technology, and is the way to leverage our technical strengths in competing with Japan.

Well, perhaps, but what evidence exists for believing this? We have heard proponents say that this will allow researchers in Chicago to run accelerator experiments in Texas or telescopes in New Mexico. All that proves is that such statements come from people entirely unacquainted with research. Another argument is by analogy with the national highway system. Like many analogies it is charming, but it begs the central question of *need*. Who really needs this capability and for what purpose? Why should we believe that it will have the claimed economic impact?

Not far behind the communication argument comes the information processing argument, holding that CAD/CAE/CAM are where the action is and that this is finally and truly the magic golden key. But this argument can be dealt with rather simply. Quite extensive studies (including those of JTEC) have shown that in no area are Japanese industries *currently leading* in design/software/computer capabilities for such things as semiconductor integrated circuits. Their technology in these areas has been judged to be comparable at best and sometimes even inferior. *However, in* *spite of that, they are still winning the high technology product race by a wide margin*.

That is not to say that CAD/CAE/CAM tools are not important. They are enormously important, but something more is obviously needed.

THE ROLE OF RESEARCH AND THE ROLE OF INCREMENTALISM

So what *is* the role of research in connection with new technological products? This is what used to be called the $64,000 question. It is a question now giving U.S. science administrators sleepless nights from coast to coast, as the price tag for both the question and the answer continuously escalate. However, even though we cannot produce a complete answer, some things are clear. One is that *basic science really can help to illuminate the pathway of technology*. This does not have to be taken on faith but can actually be demonstrated with the following argument, which in turn has a direct connection with the incremental approach.

It is an interesting and often noted fact that if one takes some numerical *measure* of the state of any given technology (the speed of airplanes, the accuracy of clocks, the complexity of very large-scale integrated logic, etc.), it often turns out to be quite accurately *log linear with time*. Furthermore this more often than not holds over many decades, until the technology finally plateaus by reaching some physical or economic limit. The clear implication here is that the incremental increase in one's capability or knowledge K, obtainable in time t, is proportional to the current level K of understanding or capability. This therefore generates an exponential and consequently leads to the log linear result. But this observation carries with it further implications concerning, for example, diagnostics. The ability to diagnose, and thereby correct or improve technological performance, is clearly enhanced by continuously advancing diagnostic techniques in the field of interest. This is one direct contributor to the exponential, and it usually depends on basic science. The same can be said regarding many other capabilities, such as metrology. Turned the other way around, this argument can therefore be used as a demonstration of the absolutely dominant role of the incremental process itself, *for without it performance would not be log linear with time*.

On the other hand, as has already been noted, basic research is indeed responsible for occasional fantastic jumps in technological capability. *But these events are rare and the associated economic payoff almost always comes from the long-term, steady, dedicated, continuous effort of incremental improvement between such jumps*. Unfortunately, our efforts in the United States tend to be very heavily focused on the former, at the expense of the latter.

SUMMARY AND CONCLUSION

The continuing decline of U.S. high technology manufacturing is not in doubt. The most significant single competitor in this arena is taken to be Japan, and this fact has led to an understandable escalation in studies of Japanese technology and management.

However, it is argued here that while such studies have undoubtedly been most useful in the past, they are now liable to yield diminishing returns. Probably a more important activity is to try to understand and act on what we *already* know. While this is certainly far from everything, it is nevertheless a lot more than nothing. Among the things we do know are at least 10 significant problem areas that are listed in the first section. All of these areas need urgent attention, and this has already been pointed out not once but many times by many different authors.

Diverting attention from these, and other, problems are two fairly recent "siren songs." These are the ideas that the culprits are really in the area of technology transfer or else in the lack of ultrahigh-speed data networking and computing. Again it is argued here that these claims are false, or at least there are no good grounds for believing them.

It has been reported that a number of years ago a member of the French National Assembly got up and said, "Everything I am about to say today I have said before, but since nobody listened it is necessary to say it again." It is not recorded whether or not he was discussing high technology manufacturing and its impact on the world economy.

II

ECONOMIC IMPACTS AND IMPLICATIONS

Technology, Productivity and the Competitiveness of U.S. and Japanese Industries

DALE W. JORGENSON AND MASAHIRO KURODA[1]

INTRODUCTION

In the early 1980s the U.S. current account balance with the rest of the world shifted from surplus to deficit, falling to almost 4 percent of the U.S. gross national product (GNP) by 1987. During this same period the Japanese current account balance moved from deficit to surplus, rising to more than 4 percent of the Japanese GNP in 1986. These developments have led to a vigorous debate on both sides of the Pacific over the competitiveness of the Japanese and U.S. economies. Did the sharp fluctuations in the Japanese and U.S. current account balances reflect a deterioration in the competitiveness of U.S. industries relative to Japanese industries? Are these fluctuations linked to a change in the relative technological performance of the two economies?[2]

Satisfactory answers to these questions require a detailed analysis of the international competitiveness of Japanese and U.S. industries. In this

[1] We are grateful to Mieko Nishimizu for her collaboration on earlier phases of the research that we report in this paper. Financial support for this research has been provided by the Japan Industrial Policy Research Institute and the Program on Technology and Economic Policy of Harvard University.

[2] International competitiveness of U.S. industries and its link to technological performance has been explored, for example, in the report of the MIT Commission on Industrial Productivity. For a discussion of technological performance and the U.S. trade balance, see M.L. Dertouzos, R.K. Lester, and R.M. Solow, *Made in America* (Cambridge: MIT Press, 1989), especially pp. 33–35.

paper we consider the competitiveness of 29 industries that make up the Japanese and U.S. economies. Our study begins with the 10 years preceding the Smithsonian agreements of 1970. In these Agreements the United States and its major trading partners, including Japan, abandoned the fixed exchange rates that had prevailed since the end of the Second World War. The dollar depreciated rapidly, from 360 yen to the dollar in 1970 to 203 yen per dollar in 1980. After a brief resurgence in the early 1980s the dollar resumed its fall after the Plaza Accord of 1985 and reached a level of less than 130 yen per dollar by the end of 1991.

We examine the relative competitiveness of U.S. and Japanese industries throughout a quarter century, 1960–1985, considering determinants of the competitive position of each industry. Our study encompasses the period of growing trade imbalances between Japan and the United States in the early 1980s. It also includes the period of the slowdown in economic growth that accompanied the energy crisis of the 1970s. We begin by comparing the relative position of U.S. and Japanese industries in 1970, on the eve of the Smithsonian Agreements. We find that almost all Japanese industries were more competitive internationally than their U.S. counterparts. By this we mean that Japanese industries could provide products to the international marketplace at prices below those available from their U.S. competitors.

The competitive strength of Japanese industries in 1970 was due almost entirely to an enormous labor cost advantage. Standardizing for important differences in education levels and taking differences in the age and sex composition of the Japanese and U.S. labor forces into account, the cost of an hour worked in Japan in 1970 was less than one-quarter the cost of an hour worked in the United States. This labor cost advantage enabled Japanese industries to overcome the formidable disadvantages of higher capital and energy costs and lower productivity. As a consequence of the dramatic appreciation of the yen after the Smithsonian Agreements of 1970, most Japanese industries lost their competitive advantage over U.S. industries by 1973. The rapid appreciation of the yen between 1970 and 1985 reduced but did not eliminate the Japanese labor cost advantage.

For the period 1960–1973, Jorgenson et al. (1987) have shown that productivity growth in Japan exceeded that in the United States for almost all industries.[3] After the energy crisis of 1973, productivity growth slowed

[3] The methodology for this study was introduced by Jorgenson and Nishimizu. They provided a theoretical framework for productivity comparisons based on a bilateral production function at the aggregate level and employed this framework in comparing aggregate output, input, and productivity for Japan and the United States; see D.W. Jorgenson, and M. Nishimizu, "U.S. and Japanese economic growth, 1952–1974: An international comparison," *Economic Journal*, vol. 88, no. 352, December 1978, pp. 707–726. Subsequently, Christensen et al. extended these comparisons to nine countries, including Japan and the United States; see L.R.

drastically in both countries. Most important, significant differences between growth rates of productivity in Japanese and U.S. industries disappeared. In this paper we extend these observations through 1985. We find that the slowdown in productivity growth in Japan and the United States after 1973 has become permanent. On average, productivity levels in Japanese industries had reached 87 percent of U.S. levels by 1980, but more recent trends reveal no further gains in relative productivity for either the Japanese or the U.S. economy. Technological competition between the two countries, as mirrored in these trends, achieved a measure of stability as much as a decade ago.

International competitiveness between Japan and the United States since 1970 has been driven almost entirely by dramatic and continuing depreciation of the dollar. Krugman has shown that trade imbalances in both countries in the early 1980s have now receded, following an adjustment process that has resulted in stunning increases in U.S. exports relative to Japanese exports.[4] In fact, since 1985 exports of the United States have grown much more rapidly than exports from any other industrialized country, reflecting the sharply rising competitive advantage of U.S. industries. This is a consequence of the falling exchange rate of the dollar vis-à-vis foreign currencies, including the yen, resulting from the Plaza Accord in 1985.

We conclude that the sharp fluctuations in Japanese and U.S. current account balances during the 1980s do not reflect changes in the relative technological performance of the two economies. While relative productivity levels for individual industries after 1980 show wide variations, there is almost no difference on average. This flies directly in the face of much conventional wisdom about the growing technological sophistication of Japanese industries and the alleged technological deficiencies of their U.S. competitors. The error in the conventional view is not in its sanguine appraisal of fast maturing Japanese technological capabilities, but in its gross underestimation of the U.S. competition.

We conclude that relative technological performance is only one determinant of international competitiveness of Japanese and U.S. industries. During the period of our study, changes in relative technological perfor

Christensen, D. Cummings, and D.W. Jorgenson, "Relative productivity levels, 1947–1973," *European Economic Review, vol. 16, no. 1, May 1981, pp. 61–94.* Their estimates of relative productivity levels are based on the methodology for multilateral comparisons developed by Caves et al.; see D.W. Caves, L.R. Christensen, and W.E. Diewert, "Multilateral comparisons of output, input, and productivity using superlative index numbers," Economic Journal, vol. 92, no. 365, March 1982, pp. 73–86. Jorgenson has updated the Japan-U.S. comparisons; see D.W. Jorgenson, "Productivity and economic growth in Japan and the United States," American Economic Review, vol. 78, no. 2, May 1988, pp. 217–222.

[4] P.R. Krugman, *Has the Adjustment Process Worked?* (Washington, D.C.: Institute for International Economics, 1991).

mance are relatively insignificant by comparison with drastic changes in such determinants as the yen-dollar exchange rate and relative labor costs. These other determinants have moved dramatically in favor of the United States since the Smithsonian Agreements of 1970 and, especially, since the Plaza Accord of 1985. Attempts to trace the trade imbalances of the 1980s to relative deterioration in the technological capabilities of U.S. industries vis-à-vis their Japanese counterparts are totally misleading as a basis for policy recommendations. Attempts to deal with trade imbalances should focus on macroeconomic policy and not on technology or trade policies.

To assess the international competitiveness of Japanese and U.S. industries, we first compare prices of inputs and outputs in the two countries at the industry level in the second section. Our second step in accounting for international competitiveness between Japanese and U.S. industries is to measure relative levels of productivity for all industries. We present comparisons of productivity levels between the United States and Japan by industry in the third section. Finally, we employ changes in relative productivity levels, relative prices of inputs, and exchange rates in accounting for changes in international competitiveness between Japanese and U.S. industries over the period 1960–1985. The final section provides a summary and conclusion.

PURCHASING POWER PARITIES

In order to construct relative prices for outputs of Japanese and U.S. industries in a common currency, we first require estimates of the purchasing power parities for the outputs of all industries. These are relative prices expressed in terms of the currencies of each country. We convert purchasing power parities into a common currency by means of the yen-dollar exchange rate. We have developed purchasing power parities for industry outputs based on the estimates of Kravis et al.[5] They have provided purchasing power parities between the yen and the dollar for 153 commodity groups for the year 1970. These commodity groups are components of the gross domestic product of each country, corresponding to deliveries to final demand at purchasers' prices.

For international comparisons we have aggregated industries in Japan and the United States into the 29 sectors given in Table 1. We estimate purchasing power parities for industry outputs, energy inputs, and other intermediate inputs by mapping the 153 commodity groups employed by Kravis et al.[6] into the industry classification system shown in Table 1. To

[5] I.B. Kravis, A. Heston, and R. Summers, *International Comparisons of Real Product and Purchasing Power* (Baltimore: Johns Hopkins University Press, 1978).

[6] Ibid.

TABLE 1 Industry Classification

No.	Industries	Abbreviation
1	Agriculture, forestry, fisheries	Agric.
2	Mining	Mining
3	Construction	Construct.
4	Food and kindred products	Foods
5	Textile mill products	Textiles
6	Apparel and other fabricated textile	Apparels
7	Lumber and wood products except furniture	Lumber
8	Furniture and fixtures	Furniture
9	Paper and allied products	Paper
10	Printing, publishing, and allied products	Printing
11	Chemical and allied products	Chemical
12	Petroleum refinery and coal products	Petroleum
13	Rubber and miscellaneous plastic products	Rubber
14	Leather and leather products	Leather
15	Stone, clay, and glass products	Stone
16	Primary metal products	Prim. metal
17	Fabricated metal products	Fab. metal
18	Machinery	Machinery
19	Electric machinery	Elec. mach.
20	Motor vehicles and equipment	Mot. veh.
21	Transportation equipment except motor	Trsp. eqpt.
22	Precision instruments	Prec. inst.
23	Miscellaneous manufacturing	Mfg. misc.
24	Transportation and communication	Trsp. comm.
25	Electric utility and gas supply	Utilities
26	Wholesale and retail trade	Trade
27	Finance, insurance, and real estate	Finance
28	Other service	Service
29	Government services	Gov. service

obtain purchasing power parities for industry outputs in producer's prices, we adjust the price indices for commodity groups in Japan and the United States by "peeling off" indirect taxes and trade and transportation margins. We estimate these margins from the interindustry transactions tables for 1970 for both countries.

We can account for movements in the relative prices of industry outputs in Japan and the United States by changes in relative input prices and changes in relative productivity levels. To obtain purchasing power parities for components of intermediate inp ut in each industry, we aggregate purchasing power parities in 1970 for goods and services delivered to that industry from other industries. To obtain the purchasing power parity for capital input, we multiply the purchasing power parity for investment goods by the ratio of the price of capital services to the price of capital goods for

Japan relative to the United States. Finally, we construct purchasing power parities for labor input on the basis of relative wage levels for each component of labor input in each industry.

Purchasing power parities (PPP) for industry output, capital, labor, energy, and other intermediate inputs in 1970 are shown in Table 2. According to our purchasing power parities for industry output in 1970, prices in Japan were higher than those in United States in only six sectors—agriculture-forestry-fisheries; construction; food and kindred products; petroleum refinery and coal products; rubber products; and finance, insurance, and real estate. The purchasing power parities for labor input in 1970 represent substantially lower costs of labor input in Japan relative to the United States.

TABLE 2 The Japanese Price Index Transformed by the PPP Index at 1970 (U.S. price = 1.0)

Industry	Output Price	Capital Price	Labor Price	Energy Price	Material Price
1 Agric.	1.02227	3.87150	0.21352	1.43929	0.94440
2 Mining	0.77726	2.87497	0.21263	1.30837	0.80470
3 Construct.	1.03629	1.62274	0.18607	1.47174	0.74581
4 Foods	1.02708	2.43016	0.21894	1.18676	0.92246
5 Textiles	0.78272	1.26204	0.24099	1.12231	0.80857
6 Apparels	0.77554	1.13210	0.18975	1.16632	0.77818
7 Lumber	0.79291	0.83225	0.22805	1.23132	0.85381
8 Furniture	0.68460	1.63768	0.22952	1.16280	0.78011
9 Paper	0.59568	1.28008	0.22170	1.16325	0.66974
10 Printing	0.79904	1.14215	0.21251	1.12034	0.69357
11 Chemical	0.67636	1.10984	0.25039	1.21555	0.74098
12 Petroleum	1.36638	2.87106	0.21846	1.44058	0.83670
13 Rubber	1.06884	2.06931	0.24042	1.15463	0.77965
14 Leather	0.72536	0.63057	0.23569	1.21586	0.81384
15 Stone	0.72066	1.44996	0.23083	1.19543	0.72436
16 Prim. Metal	0.82182	2.44286	0.25200	1.21269	0.78967
17 Fab. Metal	0.80966	1.97526	0.21072	1.21038	0.79221
18 Machinery	0.62454	1.52710	0.22564	1.22988	0.72346
19 Elec. Mach.	0.67590	2.53075	0.22308	1.17320	0.74262
20 Mot. Veh.	0.80744	6.48334	0.18581	1.14790	0.77968
21 Trsp. Eqpt.	0.91458	1.20783	0.21944	1.19623	0.78940
22 Prec. Inst.	0.71036	1.45034	0.23150	1.18503	0.75505
23 Mfg. Misc.	0.71569	1.25035	0.22549	1.22913	0.76822
24 Trsp. Comm.	0.48741	1.46822	0.22713	1.44717	0.69668
25 Utilities	0.99570	1.64236	0.26605	1.26884	0.81400
26 Trade	0.74680	1.43256	0.26889	1.25899	0.83417
27 Finance	1.04615	0.43883	0.30796	1.14881	0.90131
28 Service	0.87582	1.03805	0.30796	1.18170	0.79488
29 Gov. Service	0.30935	1.00000	0.19482	1.14261	0.81841

In that year hourly wages in Japan were 30 percent or less of U.S. hourly wages. By contrast the cost of capital in Japan averaged 30 percent higher than that in the United States in 1970. The cost of intermediate inputs in Japan, other than energy, was between 60 and 90 percent of the cost in the United States in 1970, but the cost of energy was higher in Japan.

Table 3 presents time series for price indices of aggregate value-added

TABLE 3 Aggregate Price Index Denominated by PPP Index in Japan and the United States: Value-Added Deflator, Capital Input Price, and Labor Input Price

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Value-Added		Capital Input		Labor Input	
Year	Exchange Rate	Japan	U.S.	Japan	U.S.	Japan	U.S.
1960	360.0	0.52555	0.78125	0.78566	0.80598	0.07276	0.61019
1961	360.0	0.56383	0.79141	0.87689	0.80344	0.08303	0.64323
1962	360.0	0.58677	0.80059	0.85419	0.87231	0.09436	0.65512
1963	360.0	0.61243	0.80446	0.85692	0.91738	0.10715	0.67076
1964	360.0	0.63366	0.81399	0.94763	0.96885	0.11454	0.69379
1965	360.0	0.66004	0.82973	0.96229	1.05680	0.13142	0.71378
1966	360.0	0.69136	0.86130	1.00588	1.08708	0.14518	0.75560
1967	360.0	0.72035	0.88085	1.10655	1.05501	0.16044	0.79646
1968	360.0	0.74335	0.91004	1.18636	1.07169	0.18585	0.85988
1969	360.0	0.77353	0.95530	1.25112	1.08284	0.21037	0.91525
1970	360.0	0.81298	1.00000	1.31401	1.00000	0.24265	1.00000
1971	348.0	0.86750	1.04681	1.23991	1.08036	0.28735	1.07331
1972	303.1	1.04070	1.09264	1.46593	1.17862	0.37146	1.14591
1973	271.7	1.32003	1.16598	1.78810	1.25925	0.52775	1.23109
1974	292.1	1.60104	1.28333	1.71761	1.21411	0.60654	1.35414
1975	296.8	1.64616	1.41369	1.61942	1.35635	0.70573	1.47582
1976	296.5	1.76077	1.48549	1.72552	1.49660	0.76615	1.60441
1977	268.3	2.03232	1.58890	2.02031	1.70887	0.92403	1.71226
1978	210.1	2.79563	1.71605	2.81199	1.87654	1.22518	1.83214
1979	219.5	2.67617	1.86824	2.72534	1.94851	1.22708	1.98734
1980	203.0	3.04545	2.04895	3.04414	1.95128	1.42033	2.20601
1981	219.9	2.89294	2.22929	2.82067	2.21169	1.38586	2.38345
1982	235.0	2.77932	2.36468	2.57607	2.18761	1.35692	2.53247
1983	232.3	2.86020	2.44372	2.56220	2.38257	1.37437	2.63474
1984	251.1	2.67425	2.52821	2.44013	2.66081	1.29651	2.73714
1985	224.1	3.02171	2.59609	2.80872	2.67648	1.52330	2.85215

NOTE:
(1) Observed exchange rate (yen/dollar).
(2) Value-added deflator denominated by PPP index in Japan.
(3) Value-added deflator in the United States.
(4) Capital input price denominated by PPP index in Japan.
(5) Capital input price in the United States.
(6) Labor input price denominated by PPP index in Japan.
(7) Labor input price in the United States.

and capital and labor inputs for the period 1960–1985 in Japan and the United States in terms of dollars. The first column in the table is the yen-dollar exchange rate. The second and third columns represent price indices for value-added for Japan and the United States. The second column is the Japanese price index with base equal to the purchasing power parity in 1970, divided by an index of the yen-dollar exchange rate equal to one in 1970. The third column gives the corresponding price index for the United States with base equal to one in 1970. Similarly, the fourth and fifth columns provide price indices for capital inputs in Japan and the United States in terms of dollars, and the sixth and seventh columns represent price indices for labor inputs.

Our international comparisons of relative prices of aggregate output and inputs show, first, that the Japanese economy was more competitive than the U.S. economy throughout the period 1960–1972. Japan's competitiveness deteriorated substantially after 1973 but recovered gradually due to the appreciation of the dollar in the 1980s. Second, lower wage rates have contributed to Japan's international competitiveness throughout the period, especially before the energy crisis in 1973. Lower cost of capital in the United States has contributed to the U.S. international competitiveness for most of the period, with important exceptions in 1960, 1962–1966 and 1984.

We turn next to international competitiveness of Japanese and U.S. industries. Exchange rates play the same role in relative price comparisons at the industry level as at the aggregate level. However, industry inputs include energy and other intermediate goods as well as the primary factors of production—capital and labor inputs. Table 4 gives average annual growth rates of input prices in Japan and the United States in the 1960s, 1970s, and 1980s at the industry level. The growth rates of the cost of capital in Japan were almost double those of the United States in the 1960s. Since 1970, average rates of growth in the United States have been considerably higher. The rates of growth of wage rates in Japan were substantially higher than those in the United States throughout the 1960s and 1970s. During the 1980s, however, annual rates of growth of wages in the United States exceeded those in Japan by about 1.5 percent per year.

The movements of energy input prices were similar in the two countries in the 1960s. Rates of growth of energy prices in the United States during the 1980s were about 3 percent per year higher than those in Japan. This implies that differences between energy prices in the two countries have been decreasing since 1980, in spite of the relatively high level of energy prices in Japan. The growth rates of other intermediate input prices in the United States were also higher than those in Japan after 1980. The higher growth rates of input prices in the United States since 1980—including capital, labor, energy, and other intermediate inputs—have resulted in a substantial deterioration of international competitiveness of U.S. industries relative to their Japanese counterparts.

TABLE 4 Annual Growth Rate of Factor Prices

Year	Country	Growth Rate
Capital Service Price (%)		
1960–1970	Japan	4.0815
	U.S.	2.2153
1970–1980	Japan	0.1736
	U.S.	5.6325
1980–1985	Japan	0.0245
	U.S.	7.3957
Labor Service Price (%)		
1960–1970	Japan	12.1852
	U.S.	4.5325
1970–1980	Japan	11.6958
	U.S.	8.0232
1980–1985	Japan	3.8372
	U.S.	5.2740
Energy Input Price (%)		
1960–1970	Japan	0.5428
	U.S.	0.4520
1970–1980	Japan	13.8244
	U.S.	15.2021
1980–1985	Japan	1.2482
	U.S.	4.3105
Material Input Price (%)		
1960–1970	Japan	2.1232
	U.S.	2.0492
1970–1980	Japan	7.7757
	U.S.	8.3268
1980–1985	Japan	0.5493
	U.S.	3.3107

NOTE: Annual growth rates of each price are estimated in terms of a simple average of annual growth rates by industry in each factor.

RELATIVE PRODUCTIVITY LEVELS

In this section we estimate relative levels of productivity in Japan and the United States for each of the 29 industries included in our study. Jorgenson et al. (1987) have reported relative productivity levels for the two countries for the period 1960–1979. All Japanese industries had lower levels of productivity than their U.S. counterparts in 1960. In order to compare our new results with those in our earlier paper with Nishimizu, we must note a number of revisions of our methodology. First, we have constructed intermediate input measures for the United States from a time series of interindustry transactions tables for the period 1947–1985.[7] Second, the purchasing parity index for capital input has been revised to take account of differences in rates of return on capital. Third, we were able to obtain more detailed information on wage differentials between full-time employees and other workers in Japan.

Revisions in our data base have resulted in several substantial changes in the taxonomy of industries presented for the period 1960–1979 in Jorgenson et al.[8] Since it is difficult to compare our new results with the previous ones directly due to revisions in our data base, we have presented a new taxonomy for the year 1980 in Table 5. It is difficult to assess the validity of our industrial taxonomy by using the added observations for the period 1980–1985, due to fluctuations of productivity growth by industry. As an illustration, according to the new evidence on the productivity gap between Japan and the United States in the motor vehicles industry during the period 1980–1985, the gap had closed by 1979. After 1983, however, the gap increased again due to rapid productivity growth in the U.S. industry.

The index of productivity in motor vehicles in Japan and the United States during the period 1979–1985 was as follows:

Year	Japan	United States
1979	1.00896	1.06235
1980	1.05427	1.00609
1981	1.04083	1.00706
1982	1.00539	0.99941
1983	0.99767	1.02872
1984	1.00147	1.06479
1985	1.00019	1.05392

On the basis of productivity trends before 1980 it was impossible to anticipate the rapid recovery of U.S. productivity and the deterioration of productivity in Japan in the motor vehicles industry during the 1980s. In

[7] The methodology for constructing a time series of interindustry transactions tables was originated by Kuroda; see M. Kuroda, "Method of estimation for updating the transactions matrix in input-output relationships," in K. Uno and S. Shishido, eds., *Statistical Data Bank Systems*, (Amsterdam, North-Holland: 1981). Revised intermediate input measures for the United States were presented by Jorgenson; see D.W. Jorgenson, "Productivity and economic growth," in E. R. Berndt and J. Triplett, eds., *Measurement in Economics*, Studies in Income and Wealth, vol. 53 (Chicago: University of Chicago Press, 1990), pp. 19–118.

[8] D.W. Jorgenson, M. Kuroda, and M. Nishimizu, "Japan-U.S. industry-level productivity comparisons, 1960–1979," *Journal of the Japanese and International Economies*, vol. 1, no. 1, March 1987, pp. 1–30.

evaluating the usefulness of the industrial taxonomy for 1980, we find several industries in which we were unable to project the trend of productivity gaps by simple extrapolation of trends through 1980. We can say, however, that trends of these gaps between Japan and the United States through 1980 have mostly continued through 1985.

To summarize the trend of productivity differences between Japan and the United States, we have estimated the mean and variance of the proportional gaps in the productivity between Japan and the United States by industry during the period 1960–1985. The results are shown in Table 6. The mean of proportional gap in productivity between the two countries gradually increased during the period until 1980. This movement peaked in 1982. By contrast, the variance of the relative productivity levels was fairly stable until the oil crisis in 1973 and has expanded rapidly since that time.

CONCLUSION

During the period 1960–1973, productivity growth in Japan exceeded that in the United States for almost all industries. After the energy crisis in 1973, there were very few significant differences between growth rates of productivity in Japanese and U.S. industries. However, productivity growth deteriorated substantially in both Japan and the United States. An important issue is whether the productivity slowdown is a permanent feature of both economies. To resolve this issue we can consider average productivity growth rates in Japanese and U.S. industries over the period 1960–1985:

	Japan (%)	United States (%)
1960–1965	3.269	2.709
1965–1970	4.977	0.005
1970–1973	2.077	2.033
1973–1975	-5.086	-2.123
1975–1980	1.111	0.004
1980–1985	0.003	0.008

We conclude that productivity growth in Japan and the United States has revived slightly since 1975. However the growth rates for the period 1980–1985 are well below those for the period 1960–1973, especially in Japan.

A second issue is whether productivity levels in Japan and the United States have tended to converge. While the mean of relative productivity levels between Japan and the United States has been stable since 1980, the variance has increased rapidly. This implies that convergence of Japanese and U.S. levels of productivity during the 1960s had given way to sharply divergent trends in relative productivity by industry during the 1970s and, especially, during the 1980s.

TABLE 5 An Industrial Taxonomy in Terms of Differences in Technology

Sector	Rates of Differences 1960	Average Annual Rates of Growth 1960-1970 Japan	U.S.	Rates of Differences 1970	Average Annual Rates of Growth 1970-1980 Japan	U.S.	Rates of Differences 1980	Average Annual Rates of Growth 1980-1985 Japan	U.S.	Rates of Differences 1985
Type I										
1) Agriculture	6.899	–0.615	0.895	–8.205	–1.346	0.508	–26.748	–0.031	4.935	–51.577
12) Petroleum	4.724	–1.840	1.625	–29.923	–6.077	–2.903	–61.663	–1.328	4.068	–88.646
Type II and Type V										
6) Apparels	–52.543	2.712	0.991	–36.333	1.680	1.693	–36.466	0.269	0.706	–38.652
8) Furniture	–20.675	1.145	0.544	–14.663	0.285	1.126	–23.079	0.572	0.237	–21.402
9) Paper	–7.598	1.778	1.018	0.007	–0.377	0.162	–5.390	1.849	1.151	–1.900
10) Printing	–61.847	1.260	–0.254	–46.702	–2.305	0.183	–71.583	0.070	–0.669	–67.885
13) Rubber	–66.106	2.637	1.851	–58.239	–2.719	0.043	–61.385	2.656	1.570	–55.957
14) Leather	–24.489	0.753	0.483	–21.787	–0.313	–0.150	–23.419	0.338	–0.593	–18.765
15) Stone	–29.719	1.945	0.761	–17.911	–1.091	0.200	–30.825	0.373	1.480	–36.361
18) Machinery	–13.970	1.851	0.982	–5.279	0.675	1.534	–13.905	–0.958	2.129	–29.340
24) Trsp. comm.	–12.339	3.191	1.419	5.380	0.866	1.862	–4.576	1.115	–0.717	4.580
28) Service	–46.846	1.186	0.439	–39.372	–1.323	0.510	–57.694	–1.161	–1.330	–56.849
Type III, Type IV, and Type VI										
3) Construct.	–53.684	–0.973	–0.068	–62.729	–0.682	–0.983	–59.724	–1.647	–0.062	–67.651
4) Foods	–21.625	1.030	0.609	–17.409	0.777	0.224	–11.879	–0.793	0.423	–17.957
5) Textiles	–15.657	1.619	1.393	–13.339	0.981	0.781	–11.398	0.607	0.762	–12.127
7) Lumber	–29.293	1.773	1.236	–23.919	1.463	–0.615	–3.136	4.064	1.108	11.648
16) Prim. metal	–10.759	0.642	0.269	–7.033	1.135	0.452	–0.199	0.271	0.843	–3.061
17) Fab. metal	–48.592	2.491	0.689	–30.573	0.564	0.428	–29.211	–0.121	0.318	–31.405
21) Trsp. eqpt.	–81.014	4.393	1.231	–49.394	–0.655	–0.717	–48.733	1.671	0.632	–43.579
22) Prec. inst.	–31.873	2.110	1.215	–22.928	3.325	1.184	–1.522	1.451	2.329	–5.907

	Rates of Differences 1960	Average Annual Rates of Growth 1960–1970		Rates of Differences 1970	Average Annual Rates of Growth 1970–1980		Rates of Differences 1980	Average Annual Rates of Growth 1980–1985		Rates of Differences 1985
Sector		Japan	U.S.		Japan	U.S.		Japan	U.S.	
23) Misc. mfg.	-33.986	2.610	0.623	-14.118	0.443	-0.341	-6.277	0.110	-0.250	-4.478
25) Utilities	-10.592	5.231	1.649	-4.773	-1.093	-1.483	-0.883	-0.386	-1. 112	2.764
26) Trade	-43.219	2.914	1.185	-25.933	1.204	0.648	-20.375	0.772	1.378	-23.407
27) Finance	-114.450	4.451	0.635	-76.286	1.143	0.281	-67.663	1.551	-1.380	-52.996
Type VII										
2) Mining	-7.374	3.812	0.813	22.615	1.822	-4.752	88.359	0.124	-0.850	93.227
11) Chemical	-16.312	3.271	1.523	1.195	0.741	-1.254	21.067	2.496	1.850	24.298
19) Elec. mach.	-23.664	3.331	1.686	-7.213	3.373	2.219	4.329	3.189	0.864	15.958
20) Mot. veh.	-27.117	2.974	0.538	-2.759	0.804	0.061	4.679	-1.053	0.929	-5.233

NOTE:
Type I: The United States still had an advantage in the 1980 technology. The differences in technology are expected to continue to expand in the future.
Type II: The United States had an advantage in the 1980 technology. In the 1960s the differences of technology were closing. But in the 1970s they were again expanding. So, in the 1980s they are expected to expand.
Type III: The United States had still an advantage in the 1980 technology. But their differences have been continuously closing since 1960. They are expected to close in the near future.
Type IV: The United States still had an advantage in the 1980 technology. But their differences were gradually closing in the 1970s. They are expected to close in the near future.
Type V: The United States had an advantage in the 1980 technology. The differences have been mostly constant since 1960. Their trends are expected to continue in the future.
Type VI: The United States had an advantage in the 1980 technology. Rates of productivity growth were negative in both countries. The differences are, however, expected to close in the future.
Type VII: Japan had an advantage in the 1980 technology. The differences are expected to continue to expand in the future.
If the rate of difference in technology is positive, Japan has an advantage in technology and vice versa.

TABLE 6 Mean and Variance of the Proportional Gap of Technology by Industry During the Period 1960–1985

Year	Mean	Variance	Year	Mean	Variance
1960	0.7577	0.0372	1973	0.8357	0.0378
1961	0.7676	0.0386	1974	0.8331	0.0426
1962	0.7643	0.0364	1975	0.8391	0.0500
1963	0.7642	0.0360	1976	0.8352	0.0512
1964	0.7723	0.0363	1977	0.8446	0.0623
1965	0.7717	0.0366	1978	0.8442	0.0847
1966	0.7871	0.0382	1979	0.8575	0.1017
1967	0.7975	0.0336	1980	0.8701	0.1256
1968	0.8063	0.0317	1981	0.8785	0.1483
1969	0.8214	0.0341	1982	0.8835	0.1688
1970	0.8359	0.0337	1983	0.8778	0.1768
1971	0.8269	0.0351	1984	0.8652	0.1716
1972	0.8221	0.0332	1985	0.8713	0.1492

While the United States retains a very substantial advantage over Japan in relative productivity levels, there is a small number of industries in which Japan has gained an advantage and seems likely to increase it. Perhaps equally important, the increase in the variance of relative productivity levels among industries has created opportunities for both countries to benefit from the great expansion in Japan-U.S. trade that has taken place. However, this increase is also an important source of "trade frictions" and will require continuing efforts at coordination of trade policies in the two countries.

Attempts to link trade imbalances in Japan and the United States to relative technological performance are inconsistent with the implications of the extensive body of empirical evidence we have assembled. The sharp deterioration in the U.S. current account balance and the corresponding improvement in the Japanese balance in the early 1980s took place with no changes in the relative technological performance of the two economies. U.S. international competitiveness improved sharply after the Plaza Accord of 1985, as a consequence of appreciation of the yen and other currencies relative to the dollar. This has led to a virtual explosion of U.S. exports after 1985 and a gradual decline in international imbalances in both the United States and Japan.

Removing relative technological performance from the list of explanations of trade imbalances will be a prolonged and painful intellectual process. The beginning of this process must involve relearning the economic definition of international competitiveness. "International competitiveness" is a phrase with many different meanings, so that ordinary discourse will be plagued by seemingly interminable semantic confusion. By focusing on the simple and intuitive concept of relative prices of outputs, expressed in a common currency, economists can do much to dispel this rhetorical fog. Tracing this notion of international competitiveness to its sources in costs of capital and labor and, most critically, the yen-dollar exchange rate can help illuminate trade policy issues on both sides of the Pacific.

Macroeconomic and Schumpetarian Features of Japanese Innovations in the 1980s

MASARU YOSHITOMI

The purpose of this paper is twofold. One is to identify various channels whereby Japanese R&D activities and innovations contributed to manufacturing output growth in the 1980s. These channels include the relationships between R&D activities on the one hand and total factor productivity, business investment, quality and prices of products, and diversification of business activities by enterprises on the other. The importance of increased interindustry effects of R&D activities through input-output relations is stressed. The other purpose is to explain what accounts for the dynamic technological developments in Japan during the 1980s. Japan's Schumpetarian system appears to be responsible, but a more fundamental question is what makes it possible for Japan's economic system to be both dynamic in Schumpetarian innovation and consistent with Ricardian static comparative advantage.

TOTAL FACTOR PRODUCTIVITY, R&D AND INNOVATIONS

In the 1980s, an increase in total factor productivity contributed to the growth of real output by about 4 percent per year in Japanese manufacturing (see Table 1). This contribution was higher than in the 1970s and was comparable to that of the second half of the 1960s during the high-growth period.

Real output growth can exceed the weighted growth of capital and labor inputs. Weights are given by factor shares of output. The growth of output beyond that contributed by capital and labor inputs should be attributable to improvements in productivity of both capital and labor, that is, total factor productivity. Technically, the production function can be specified as a Cobb-Douglas function, with the coefficients of capital and labor constrained to be equal to their shares in output or income. [1] On this basis, total factor productivity can be estimated as residuals that cannot be explained by contributions of capital and labor input to output.

TABLE 1 Contributions of Factor Inputs to Output Growth in Japanese Manufacturing, 1970–1988

	Annual Rates (%)	
	1970–1980	1980–1988
Real gross domestic product (GDP)	5.9	6.5
Capital inputs, increase rates	7.1	6.0
Contribution to GDP	2.4	1.9
Labor inputs, increase rates	-0.1	0.8
Contribution to GDP	0.0	0.5
Total factor productivity contribution to GDP	3.5	4.1

SOURCE: Economic Planning Agency.

Industry comparisons in Japanese manufacturing suggest that the higher the R&D expenditure, the higher is the growth rate of total factor productivity. For instance, the electrical machinery industry, which registered the highest R&D expenditure per total wages and business investment among industries, enjoyed the highest growth rate of total factor productivity.

In manufacturing, business investment was strongly and favorably influenced by R&D expenditure. The elasticity of real business investment (divided by real total sales) with respect to real R&D expenditure (divided by real total sales) is found to be about 0.6 with the distributed lag of R&D over the present and preceding three quarters (see Table 2).

The stock of R&D capital rather than the flow of R&D expenditure should contribute to the growth of output as in the case of physical capital inputs. Furthermore, the net rather than gross stock of R&D capital is more meaningful, since amortization or depreciation of technology and knowledge is extremely rapid though it is difficult to measure. Since total factor productivity may be interpreted as a measure of the state of technological

[1] A Cobb-Douglas production function with constant returns to scale is specified as $Q_t = Ae^{t} K_t L_t^{(1-)}$ with Q = output, L = labor, K = capital, t = time, A is a constant, is capital's share of output, and is the residual, or the rate of growth of total factor productivity.

progress that enhances the productivity of both capital and labor, its key determinant is the net stock of R&D capital. An International Monetary Fund study has found that in Japan the net stock of R&D capital rose at an annual rate of 9.25 percent in the 1980s, contributing nearly one percentage point to the overall real growth in gross national product (GNP) of about 4 percent per year in the decade.

TABLE 2 Estimates of Investment Function, Selected Manufacturing Industries Combined (log linear)

	Independent Explanatory Variables				
Dependent Variable	R&D per Sales	Operating Rates	Profit Rates	Investment Rates	R2
Investment per sale	0.58	0.43	0.04	-0.03	0.91
(*t* values)	(6.60)	(2.08)	(4.67)	(-1.78)	

SOURCE: The Bank of Japan, Monthly Research, "On the Efforts of R&D Activities in Recent Years," October 1990.

It can be also observed from industrial comparisons that the higher the rate of increase in R&D expenditure, the higher is the rate of increase in labor productivity (output/labor), and hence the lower is the rate of increase in output prices.

Furthermore, the increased total factor productivity appeared to be profoundly associated with the quality improvement of products in the 1980s, since real GNP (which should reflect higher value added of output) in manufacturing grew faster than the production index (which simply reflects the volume of output) of manufacturing in the decade, while both figures grew more or less in parallel in the preceding decades.

In the 1960s and 1970s, Japan's manufacturing industry witnessed an increase in labor productivity (manufacturing gross domestic product (GDP/man-hour) that was accompanied by an increase in capital/output ratio (manufacturing GDP/real capital stock). In sharp contrast, however, the 1980s witnessed not only continued increases in labor productivity but also declines in capital/output ratio (i.e., increases in capital productivity; see Table 3).

Relative price changes between capital and labor promote substitution of capital for labor. In the 1980s, such substitution advanced, thanks to absolute stability or even absolute declines in prices of capital goods in the face of wage increases. This decline in the deflator of capital goods was particularly evident for electrical machinery and, to a lesser extent, general machinery, in contrast to construction machinery whose deflator actually rose. Declines in the prices of semiconductors and computers greatly contributed to these absolute price falls.

TABLE 3 Capital/Output Ratios by Industry in the 1980s

	1980	1988
Total industry	1,530	1,941
Manufacturing	1,917	1,878
Nonmanufacturing	1,354	1,977

SOURCE: Economic Planning Agency, National Accounts.

Thus, numerically controlled machinery nearly tripled in the 1980s. The number of installed industrial robots in Japan at the end of the 1980s was far greater than that of the United States and Germany (see Table 4). FMS (flexible manufacturing system) and CIM (computer-integrated manufacturing) have also been introduced in recent years.

These technological developments have made it possible for enterprises to produce much greater varieties with smaller volumes of each product in a shorter product cycle, to satisfy diversified individual demands of users and consumers in markets. The product cycle of capital goods has also shortened, and the machinery lease industry has grown rapidly.

Together with these developments, the aforementioned strong business investment has resulted, through greater addition of new investment to existing capital stock, in younger vintage of installed capital. The vintage of

TABLE 4 Industrial Robots in Operation, End of 1989

	Units (thousands)
Japan	220
United States	37
West Germany	22
Italy	10
France	7
Other	23

NOTE: Industrial robot is defined as multipurpose machinery with self-control mechanisms and reprogramming capability.
SOURCE: International Federation of Robots.

capital began to get older after the end of the high-growth period. In the second half of the 1980s, however, the vintage of capital stock peaked at just over nine years and started to decline somewhat in the manufacturing sector.

Computerization and information technologies have promoted greater business investment not only in manufacturing but also in nonmanufacturing industries such as finance, insurance, transportation, telecommunications, and distribution (wholesale and retail). In fact, the capital/labor ratio increased more rapidly in the nonmanufacturing sector than in manufacturing in the 1980s, contributing to an improvement in the low level of labor productivity in nonmanufacturing relative to manufacturing in Japan (see Table 3).

R&D also makes it possible for an enterprise in a declining industry to diversify into other industries and to compete with existing enterprises in the industries new to the entrant. In the 1980s, such proliferation of Japanese business participation in more promising industries was evident particularly for declining industries such as textiles, nonferrous metals, and iron and steel.

Total factor productivity in a given industry can be affected not only by its own R&D activity but also by the improvement of the quality of inputs into the industry. The latter is mainly the result of R&D activities of input-supplying industries. The fruits of input suppliers' R&D efforts, as embodied in intermediate and investment goods, can thus be captured by their users. This interindustry technology flow can be calculated by using input-output tables, as shown in Table 5.

TABLE 5 Total R&D Intensity, Direct and Indirect (%)

	1975	1980	1985	1986	1987	1988	1989
Agriculture	0.600	0.612	0.708	0.789	0.846	0.861	0.788
Mining	0.712	0.687	0.705	1.020	1.348	1.339	1.404
Construction	0.806	0.808	1.044	1.187	1.234	1.272	1.313
Foods	0.830	0.841	1.043	1.136	1.286	1.261	1.317
Textiles	0.955	1.096	1.429	1.355	1.834	1.671	1.832
Papers and pulps	0.885	0.840	1.312	1.307	1.413	1.521	1.595
Chemicals	1.928	3.718	5.343	6.190	6.466	6.940	7.130
Petroleum and coal	0.766	0.795	0.828	1.272	1.540	1.662	1.673
Ceramics	1.200	1.292	1.996	2.583	2.621	2.488	2.691
Iron and steel	1.493	2.147	3.692	4.141	4.170	4.272	4.362
Nonferrous metals		1.584	2.789	3.139	2.815	3.464	2.662
Metals	1.108	1.480	2.188	2.324	2.193	2.271	2.255
General machinery	1.854	2.680	3.121	3.628	3.814	3.509	3.822
Electrical machinery	2.157	4.565	6.431	7.134	7.297	6.995	7.572
Transport machinery	1.616	3.444	5.225	5.593	5.674	5.976	6.130
Precision machinery	1.512	3.176	5.337	5.311	5.870	6.318	5.913

SOURCE: Keizai Kikakucho (Economic Planning Agency), *Heisei San Nendo Keizai Hakusho* (Economic White Paper 1991), (Tokyo: Okurasho insatsu kyoku, 1991).

The direct input of R&D into a given industry increased in all industries except agriculture from 1980 to 1988, particularly in the four machinery sectors and in chemicals. More interestingly in terms of indirect inputs of R&D into a given industry from all other industries, every industry benefited more from the rapid technology advance of other industries. In particular, the transport and the iron and steel industries benefited most from such indirect technology advances. In contrast, the electrical and precision industries enjoyed relatively fewer benefits from other industries, since they received proportionately less inflow of embodied R&D. These two industries have the highest total direct and indirect intensity of R&D, but mainly thanks to their own high input of R&D (Table 5).

SCHUMPETARIAN FEATURES OF JAPAN'S INNOVATIONS

All in all, these dynamic technological developments contributed greatly to overcoming the recessionary effects of the drastic appreciation of the yen and to upgrading industrial and trade structures in Japan in the 1980s. What accounts for such dynamic developments? Japan's "Schumpetarian system" was responsible.

There is a widespread notion that Japan's success in industrial development cannot be understood in the context of traditional economic notions of comparative advantage. It is often claimed that Japan has "created" comparative advantages for strategic industries. A distinction is made between Ricardian or allocative efficiency on the one hand and dynamic or Schumpetarian efficiency on the other. It is asserted that there can be a real conflict between short-term Ricardian efficiency (specializing in the production of, say, textiles and black and white televisions) and long-term dynamic efficiency (say, specializing in high-income elasticity products such as color televisions and word processors). Accordingly, it is claimed that Schumpetarian, not Ricardian, efficiency clearly determined economic policymaking in Japan and that this distinction has made Japan's industrial development successful.

The fundamental question imposed by this argument is whether there is any conflict between the static efficiency of resource allocation based on comparative advantage (which would require the elimination of monopolies) on the one hand and Schumpetarian innovation and the resultant dynamic evolution of comparative advantage on the other.

There are two important aspects to Schumpetarian innovation. One is that technical change is not an accidental by-product of "residuals" of economic activities, but the result of deliberate efforts on the part of enterprises through R&D competition and organizational reform. The other is that in the basic Schumpetarian framework, such innovation or new technical and organizational knowledge is at least temporarily appropriable by allowing innovative firms to establish monopoly positions. Over time, however, new technologies become public goods through imitation by rivals. Thus, the incentive for innovation depends on the expectation of the innovator that he will be rewarded with such temporary profits.

Technological advance has interesting "dual" features, namely, (1) it possesses the characteristics of a public good (i.e., use by one firm does not preclude its use by another) and (2) it is largely provided by private firms that do R&D. In the neoclassical production function with technological change, output can increase more than proportionately with increases in capital and labor. This extra output growth is attributed to total factor productivity, as noted above. In this production function, however, total factor productivity or the technological advance is treated as if it were a pure public good. If that were the case, any technological advantages could not be compensated for in the market. Innovators who succeed in applying new technology to commercial production should be rewarded by being able to appropriate extra profits, since innovation is not an unintended side effect of other activities. If firms succeed in innovation in terms not only of new production processes and new products but also of organizational and managerial reforms, they will be rewarded by extra profits thanks to achieving higher productivity, lowering production costs, securing higher quality, and meeting customers' new demands for differentiated products. However, the Schumpetarian process of innovation does not stop here. Intense competition among rivals inevitably leads to spillovers from innovation. Eventually, the technical advance and organizational changes that have contributed to the innovation will become public goods, thereby enhancing the overall economic well-being.

This Schumpetarian world is, therefore, an extremely competitive one, preventing firms from reaping any permanent monopoly profits on the basis of innovation. This dynamic competition results in the equally dynamic development of national resource endowments themselves in the form of increasing abundance of R&D and skilled labor inputs per unit of output, relative to other national resources. For this reason, the Schumpetarian dynamic evolution of comparative advantage is not at all inconsistent with the Heckshire-Ohlin trade theory, once one admits the dynamic and endogenous creation of national resource endowments themselves through deliberate policies at both enterprise and government levels.

In general, growth and Schumpetarian technology efficiency cannot be obtained by totally ignoring Ricardian comparative advantage. Comparative advantages are bound to evolve naturally as an economy accumulates capital and skills. In other words, the economic determinants of national comparative advantage naturally evolve, as the *relative* abundance or scarcity among endowed production resources (land, raw materials, labor, capital, skills, and R&D) dynamically changes through economic development.

As demonstrated by various studies, Japan has registered the dynamic changes in comparative advantage from unskilled labor-intensive to capital-intensive and further to R&D-intensive manufactured products.

Japan's innovation experience suggests that intense competition among a relatively large number of enterprises in a given industry not only encourages Schumpetarian innovations by rewarding innovators with above-average profits but also expedites spillovers of the innovation through competition and imitation among rivals. The dynamic evolution of comparative advantage through Schumpetarian innovations supported by R&D activities of private enterprises must be consistent with the static comparative advantage at a given point in time. This is because the relative endowments of domestic resources dynamically evolve over time through increasing inputs of R&D and physical capital relative to labor and natural resources. At a given time the domestic resource endowments should determine comparative advantage through efficient resource allocation due to intense competition.

The Changing Place of Japan in the Global Scientific and Technological Enterprise[1]

DAVID C. MOWERY AND DAVID J. TEECE

INTRODUCTION

During the past 20 years, Japan's role within the global network of public and private institutions that influence the creation and adoption of new technologies has changed. Along with dramatic structural change in the Japanese economy, this period has witnessed a transformation in Japanese technological capabilities. From its position in the 1960s as an economy that relied extensively on the transfer and modification of externally developed technologies, Japan has emerged as an economy with many firms that define the technological frontier in their industries.

This transformation in Japanese technological capabilities has created complex challenges for U.S. managers and public officials. The rapidly expanding network of "strategic alliances" among U.S. and Japanese firms has fueled concern that the pursuit by U.S. managers of corporate interests may not coincide with the advancement of U.S. national economic interests. The contrasting structure of the U.S. and Japanese "national innovation systems" means that U.S. firms may have more difficulty accessing Japanese scientific and technological research than Japanese firms have accessing

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U.S. research activities and results.[2] Added to these and other challenges for public policy is that of assessing the "lessons," if any, of postwar Japanese government industrial and technology policies for a U.S. economy that has produced minimal growth in overall productivity or median household incomes during the past two decades.

Our survey of these issues begins with a brief overview of Japan's emergence as a producer of "state-of-the-art" technology during the past 20 years. We then describe U.S. firms' evolving links to Japanese technology development through alliances, R&D activities conducted in Japan, and other means. The next section discusses some of the complexities for corporate managers and public policy created by these links and by other efforts by policymakers and scholars to divine the "lessons" of Japanese policy.

JAPAN'S CHANGING TECHNOLOGICAL POSITION, 1960-1990

A number of indicators suggest that Japanese firms have progressed during the postwar period from borrowing, modifying, and successfully commercializing foreign technologies to operating at the technological frontier. No individual indicator is definitive, but together they are suggestive. Okimoto and Saxonhouse noted that the ratio of Japanese exports of technology to imports increased from 0.12 in 1971 to 0.30 in 1983.[3] This indicator reflects historical trends in licensing and therefore includes royalty payments for technologies licensed years ago. The ratio of technology exports to imports in new contracts alone, however, has risen from 1 in 1972 to 1.76 in 1984—in other words, Japanese firms are now net exporters of intellectual property as measured in new contracts.[4] The average annual rate of

[2] See Christopher Freeman, *Technology Policy and Economic Performance: Lessons from Japan* (London: Frances Pinter, 1987) and Richard R. Nelson, ed., *National Innovation Systems: A Comparative Study* (New York: Oxford University Press, forthcoming).

[3] See Daniel I. Okimoto and Gary R. Saxonhouse, "Technology and the Future of the Economy," in K. Yamamura and Y. Yasuba, eds., *The Political Economy of Japan,* vol. 1, *The Domestic Transformation* (Stanford: Stanford University Press, 1987), pp. 384–395.

[4] This conclusion is corroborated by other data from the Japan Science and Technology Agency, reported in the *1985 Japan Economic Almanac* : "Technology exports in fiscal 1983 totaled 6,403 cases, up a significant 35.1 percent of 1,665 cases from the previous year. On the other hand, technology imports came to 7,839 cases, up 13.0 percent or 903 cases. In this area, imports continue to surpass exports. However, what deserves attention is that exports of new patents, excluding exchanges on a continuous basis, have stayed substantially above imports since the latter half of the 1970s, showing a stable surplus. Exports of new patents in fiscal 1983 stood at 2,494 cases as compared with 1,073 cases of imports, with a surplus of Y32.5 billion" See Y. Nakazora, "Science and Technology: Private sector holds initiative in research and development," *Japan Economic Almanac 1985* (Tokyo: Nihon Keizai Shimbun, 1985). For a report of similar findings for fiscal 1984, see *Industrial Review of Japan: 1984* (Tokyo: Nihon Keizai Shimbun, 1984).

growth in Japanese payments for imports of technology declined from 31 percent in the 1950s to 6 percent in the late 1970s, according to Uekusa.[5]

Alone among industrial nations, Japan registered an increase, rather than a decrease, in the number of patents received per scientist and engineer during 1967–1984, as well as an increase in the number of patents received in foreign countries. Pavitt and Patel point out that on a per capita (adjusted by home-country population) basis, Japanese patenting in the United States increased by more than 650 percent during the period from 1963–1968 to 1980–1985, far more than any other industrial economy.[6] The U.S. National Science Foundation (NSF) reported in 1988 that Japanese firms accounted for the largest single share of foreign-origin U.S. patents.[7] A comparison of U.S. patenting by U.S. and Japanese firms in 1975 and 1986 reveals dramatic improvements in Japanese patenting performance, relative to that of U.S. firms, in selected technologies (Table 1). Moreover, according to the NSF report, Japanese-origin U.S. patents were cited more than proportionately in other patent applications, an indicator of the high quality of the Japanese patents.[8] Japan outstripped the combined totals of Germany, France, and England in patents granted in the United States in 1987 (Table 2).

Other indicators of technological performance also suggest considerable Japanese strength. Technology adoption is a critical factor in national competitive performance, and in some technologies Japanese adoption performance appears to exceed that of the U.S. economy. The rate of adoption and intensity of utilization of advanced manufacturing technologies (including robotics, computer-integrated-manufacturing workcells, and flexible manufacturing systems) in Japanese manufacturing both considerably exceed

[5] See M. Uekusa, "Industrial Organization," in K. Yamamura and Y. Yasuba, eds., *The Political Economy of Japan*, vol. 1, *The Domestic Transformation* (Stanford: Stanford University Press, 1987).

[6] See K. Pavitt and P. Patel, "The International Distribution and Determinants of Technological Activities," *Oxford Review of Economic Policy* 4, 1988, pp. 35–55.

[7] See National Science Foundation, *The Science and Technology Resources of Japan: A Comparison with the United States*, NSF report 88-318 (Washington, D.C.: 1988), p. 33.

[8] Ibid., p. xii. "Given their total representation in the U.S. patent system, Japanese patents account for 45 percent more of the top I percent most highly cited U.S. patents than expected. The highest citation rates for Japanese patents are in the automotive, semiconductor electronics, photocopying and photography, and pharmaceuticals patent classes." The relatively high quality of Japanese firms' U.S. patents, however, may reflect some tendency of these firms to seek U.S. patents only for their most important technological advances. Taylor and Yamamura argue that Japanese firms are far more likely to seek domestic patent protection for minor technical advances than are U.S. firms: see S. Taylor and K. Yamamura, "Japan's Technological Capabilities and its Future: Overview and Assessments," in G. Heiduk and K. Yamamura, eds., *Technological Competition and Interdependence: The Search for Policy in the United States, West Germany and Japan* (Seattle: University of Washington Press, 1990).

TABLE 1 U.S. and Japanese Shares of Total Patents Granted in the United States for Selected Technologies: 1975 and 1986 (percentage)

	United States		Japan	
Selected Technologies	1975	1986	1975	1986
Lasers	63	50	14	35
Telecommunications	66	52	14	26
Steel and iron	48	37	18	29
Internal combustion engines	54	28	17	44
Semiconductor devices and manufacture	68	57	13	29
Jet engines	66	60	4	9
General-purpose programmable digital computer systems	77	69	5	19
Robots	63	50	20	29
Machine tools—metalworking	65	51	8	17
All technologies	65	54	9	19

SOURCE: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, unpublished data. National Science Foundation, *The Science and Technology Resources of Japan: A Comparison with the United States*, NSF report 88-318 (Washington, D.C.: 1988).

their levels in U.S. manufacturing.[9] Other research has documented the ability of Japanese automotive firms to bring new models to market more rapidly than U.S. auto firms, and Mansfield's research indicates that for technologies based on sources of knowledge outside of the firm, Japanese firms exhibit significantly shorter development and commercialization cycles.[10] Mansfield's research also indicates that Japanese firms devote roughly

[9] See C. Edquist and S. Jacobsson, *Flexible Automation: The Global Diffusion of New Technology in the Engineering Industry* (New York: Blackwell, 1988); K. Flamm, "The Changing Pattern of Industrial Robot Use," in R.M. Cyert and D.C. Mowery, eds., *The Impact of Technological Change on Employment and Economic Growth* (Cambridge, Mass.: Ballinger, 1988); and E. Mansfield, "The Diffusion of Industrial Robots in Japan and the United States," Research Policy, vol. 18, 1989, pp. 183–192.

[10] See Kim B. Clark, W.B. Chew and Takahiro Fujimoto, "Product Development in the World Automobile Industry," *Brookings Papers on Economic Activity* (Washington, D.C.: 1987), pp. 729–771; Kim B. Clark and Takahiro Fujimoto, *Product Development Performance: Strategy, Organization and Management in the World Auto Industry*. (Boston: Harvard Business School Press, 1991); and Edwin Mansfield, "Industrial Innovation in Japan and the United States," *Science*, September 1988.

TABLE 2 Applications (Registrations) in Selected Countries, by Nationality, 1989

Nationality of Applicant	Country of Application: Japan	United States	FRG	France	England	Soviet Union	Others
Japan	317,609 (54,743)	33,104 (20,168)	14,454 (6,888)	10,765 (4,294)	12,938 (5,440)	202 (102)	43,598 (13,932)
United States	17,563 (3,799)	82,956 (50,185)	18,693 (7,135)	17,483 (6,118)	19,598 (6,859)	1,664 (167)	161,087 (44,092)
FRG	7,436 (1,813)	13,245 (8,303)	43,265 (16,904)	13,471 (6,832)	13,075 (6,179)	830 (240)	87,999 (32,720)
France	2,624 (654)	4,960 (3,140)	5,115 (2,752)	15,468 (8,301)	4,920 (2,422)	291 (86)	37,545 (15,139)
England	2,861 (432)	6,502 (3,100)	4,778 (1,637)	4,461 (1,471)	24,031 (4,234)	489 (50)	43,242 (10,470)
Soviet Union	357 (108)	570 (161)	459 (227)	365 (126)	403 (87)	146,021 (83,348)	5,420 (1,552)
Other	9,014 (1,752)	20,323 (10,482)	15,663 (16,690)	12,929 (5,737)	15,269 (5,676)	2,311 (584)	
Total	357,464 (63,301)	161,660 (95,539)	102,427 (42,233)	74,942 (32,897)	90,234 (30,897)	151,808 (84,577)	
% of Foreign Applications	11.1 (13.5)	48.7 (47.5)	57.8 (60.0)	79.4 (74.8)	73.4 (86.3)	3.8 (1.5)	

NOTE: Figures in parentheses are registrations.
SOURCE: Kagaku gijutsu-cho (Science and Technology Agency)(ed.), *Kagaku gijustu hakusho heisei 3 nendo: Kagaku gijustu katsudo no guroobarizeeshon no shinten to wagakuni no kadai* (1991 White Paper on R&D: Developments Towards the Globalization of R&D and Japan's Tasks), (Tokyo: Okurasho Insatsukyoku, 1991).

twice as large a share of their R&D budget to process research as U.S. firms. Interestingly, Mansfield's econometric analyses suggest that the returns to R&D investments in Japanese industry substantially exceed those in U.S. industry.[11]

This remarkable record of technological achievement has rested largely on R&D funding from private industry, rather than from government. The

[11] Edwin Mansfield, "Industrial R and D in Japan and the United States: A Comparative Study," *American Economic Review Papers and Proceedings*, 1988.

share of national R&D that is privately financed is higher in Japan than in the United States or other industrial countries. The share of national R&D expenditures financed by the Japanese government was only 20 percent in 1987, and this included grants-in-aid to national and private universities. The comparable figure for the United States in 1987 was 49 percent. The large military R&D budget in the United States accounts for much of this difference, but the Japanese share of R&D financed by the private sector is larger than that for the United States even if we consider only nondefense R&D.[12] When military R&D expenditures are removed from the figures for both countries, the share of gross national product (GNP) devoted to R&D in Japan has exceeded the American figure since the early 1960s.

The U.S.-Japan contrasts in the direct role of government R&D funding are linked to other important differences in the structure of the U.S. and Japanese "national research systems" (a term meant to include both public and private research organizations). Along with a relatively open market for imports and foreign investment (albeit one that has faced significant demands for protection in recent years), the United States maintains a relatively open research system. More than 50 percent of the basic research performed within the U.S. economy is carried out within universities (including federally funded R&D centers, or FFRDCs). The structural characteristics of the U.S. R&D system, with its high mobility of engineers, scientists and entrepreneurs among firms, heavy reliance on university research for basic science and training, and on small firms for technology commercialization, mean that access by foreign firms to U.S. scientific and technological advances is relatively easy.[13]

The relative importance within the Japanese R&D system of "open" and "closed" research institutions, respectively universities and private firms, contrasts with that of the United States. Comparative statistics suggesting that Japanese universities account for a larger share of that nation's total R&D investment overstate the performance of R&D within Japanese universities; moreover, the contribution of Japanese universities to basic knowledge historically has been modest in many areas. The Japanese economy's system of industrial finance and governance also makes it difficult for U.S. and other foreign firms to gain access to industrial technologies or innovations through acquisitions of firms or intellectual property.

The structure of both the Japanese and U.S. R&D systems is chang

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[12] R&D expenditures constituted roughly 1.70 percent of Japanese GNP in the years 1975–1978. This ratio rose to 1.80 percent in 1979 and to 2.77 percent in 1985, exceeding the U.S. GNP share of 2.4 percent in that year.

[13] See Stephen Cohen, David Teece, Laura Tyson, and John Zysman, "Competitiveness," in *Global Competition: The New Reality*, vol. III (Washington D.C.: President's Commission on Industrial Competitiveness, 1985) for an early statement on this issue.

ing,[14] but in the near future, the U.S. system is likely to remain unparalleled as a performer of basic research, even as the Japanese R&D system strengthens its already impressive capabilities in the creation, modification, and adoption of technology. Among other things, the deeply rooted nature of differences in the structure of the Japanese and U.S. R&D systems means that changes in public policy will work slowly and incompletely to remove structural impediments to access.

U.S. FIRMS' GROWING LINKS WITH THE JAPANESE R&D SYSTEM

The rise of Japan as a technological powerhouse has been paralleled by growth in the importance of the Japanese market for consumer and industrial goods. Foreign firms have pursued a number of approaches to improving their access to Japanese technology and markets, including the establishment of R&D facilities in Japan and the development of complex "strategic alliances" with Japanese firms. Remarkably, in view of the urgency and importance of this issue for U.S. public policy and private managers, federal agencies provide only the most rudimentary data on U.S. and foreign R&D investment in Japan or on the growth of U.S.-Japanese interfirm alliances. In this section, we review the development of both of these approaches to access, relying on fragmentary data from the Japanese Ministry of International Trade and Industry (MITI) and other sources.[15] One of the most important implications of the growth of Japanese technological capabilities is the need for better data on the nature of private and public relationships between U.S. and Japanese entities in technology development, transfer, and exchange. All too often, U.S. policy toward Japanese industrial R&D is formulated in a factual vacuum.

[14] For example, Japanese university research has played an important role in the development of molecular beam epitaxy (MBE), a semiconductor component manufacturing process: "While universities played a minor role in MBE-research in the early 1980s in Japan, they are ten years later contributing very actively, especially in research related to quantum materials and quantum-effect devices. The pattern is similar in other countries and partly a consequence of changes in MBE technology and related research topics. The development of MBE technology has, for example, become increasingly dependent on an understanding of the basic mechanisms of the MBE growth process and as the sophistication of MBE technology has grown it has become possible to grow materials and structures which can be used to study scientifically increasingly more interesting physical effects, changes which both have served to attract academic scientists to MBE-research. Although Japanese universities have responded vigorously to the new challenges opening up, their response has been weaker, in quantitative terms, than that of the American universities but comparable to that of European universities." See L. Stenberg, "Molecular Beam Epitaxy—A Mesoview of Japanese Research Organization," unpublished manuscript, Research Policy Institute, University of Lund, Sweden, p. 56.

[15] We are indebted to Dr. Takebi Otsubo of the Nomura School of Advanced Management for his assistance in obtaining these data.

Foreign Patenting and R&D Activity in Japan

Patent activity by foreign firms in postwar Japan indicates that foreign firms have had a long-standing interest in utilizing their technology in Japan. Though the data we have found are extremely sketchy and relate only to patent applications, they indicate that foreign firms accounted for 23.2 percent of the total of all patent applications in Japan in 1970, although by 1978 this had fallen to 14.8 percent.[16] Chemicals was the most active of these sectors in foreign patenting within Japan during the 1970–1978 period. The United States accounted for 42.7 percent of the total number of foreign patent applications (30,089) in 1989. Germany was the second most significant applicant in 1989, with 19.4 percent of the total (see Figure 1). Table 2 indicates, however, that foreign firms have been less active in patenting in Japan than they have in the United States, Germany, France, or England.

Of perhaps greater interest are the R&D activities of foreign firms in Japan.[17] Table 3 contains data from a MITI survey of growth in foreign R&D laboratories in Japan during 1975–1990 in manufacturing, which account for the vast majority of foreign R&D activity.[18] The number of foreign-owned Japanese R&D facilities in manufacturing grew rapidly during this period, from 51 in 1975 to 123 in 1990, by 1990, this study suggests, total foreign R&D expenditures within Japan amounted to more than 200 billion yen, more than $1.5 billion. Interestingly, despite widespread perceptions of Japanese technological strengths in electronics and manufacturing process technologies, Table 3 suggests that the chemical and pharmaceutical industries account for the largest number of foreign-owned R&D facilities in both 1975 and 1990 and the largest share of foreign firms' investment in 1990. A substantial portion of foreign pharmaceutical firms' R&D investment almost certainly is linked to their efforts to obtain regulatory approval for the introduction of new drugs into the Japanese market. Although foreign clinical trial data are increasingly acceptable to Japanese regulatory authorities, the use of domestic medical personnel and researchers for such trials remains a more effective strategy for gaining regulatory approval. Much of foreign pharmaceutical firms' R&D investment, therefore, appears to be linked to growth in the Japanese consumer market.

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[16] Kagaku gijutsu-cho (Science and Technology Agency), ed., *Kagaku gijutsu hakusho heisei 3 nendo: Kagaku gijutsu katsudo no guroobarizeeshion no shinten to wagakuni no kadai* (1991 Science and Technology White Paper: Developments towards the Globalization of R&D and Japan's Tasks), (Tokyo: Okurasho Insatsukyoku, 1991), p. 374.

[17] Patent applications in Japan undoubtedly primarily reflect technology developed outside of Japan.

[18] For purposes of the survey, "foreign-owned R&D" establishments are defined as those operated by foreign firms or joint ventures in which non-Japanese firms control more than 51 percent of the equity.

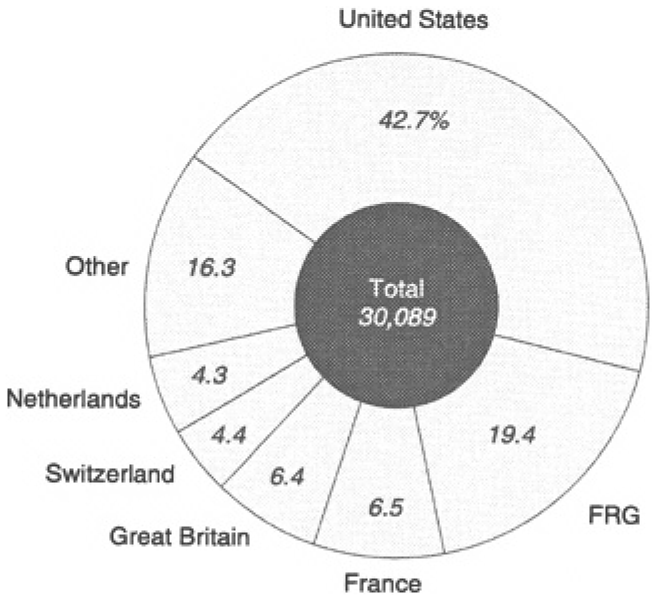

Figure 1 Number of patent applications by foreigners in Japan, 1989, by country.
Source: Kagaku gijutsu-cho (Science and Technology Agency) (ed.), Kagaku gijutsu hakusho heisei 2 nendo (1990 White Paper on R&D), (Tokyo: Okurasho insatsukyoku, 1990).

A separate tabulation compiled as part of the MITI study contains data on the number and expenditure of Japanese R&D facilities owned by U.S. and non-U.S. firms in 1990 (including nonmanufacturing industries). According to this analysis, U.S. firms operated 83 R&D laboratories at a cost of nearly 83.5 billion yen in 1990. European firms accounted for 58 laboratories but invested a larger amount, more than 122 billion yen. The apparent differences in the average size of U.S. and European R&D laboratories in Japan are not explained in the study, but may reflect differences in the industrial composition of U.S.-and European-owned R&D laboratories within Japan. The European R&D presence within Japan may contain a larger share of chemical and pharmaceutical firms, which typically operate large laboratories, than the U.S. industrial R&D investment, which contains a higher share of software and electronics firms. In the absence of additional data, however, any such conclusion is purely speculative.

These data on foreign firms' R&D investment in Japan differ somewhat from the portrait of foreign firms' innovative activities in Japan presented by Cantwell.[19] Cantwell's data are based on U.S. patents received by large U.S. and foreign firms' Japanese research facilities, and suggest that the contribution of foreign-owned R&D in Japan during 1978–1986 was greatest in motor vehicles, scientific and measurement instruments, and electrical equipment (including semiconductors). The modest contribution of foreign-owned pharmaceuticals research in Japan to these firms' U.S. patents is consistent with our earlier discussion of this R&D investment in Japan, much of which is concerned with clinical testing and approval of new drugs for the Japanese domestic market.

TABLE 3 Foreign R&D Facilities in Japan, 1975 and 1990; Foreign Firms' R&D Expenditures in Japan, 1990

	No. of Labs 1975	No. of Labs 1990	R&D Expenditure 1990 (billion yen)	R&D Expenditure 1990 (million dollars)
Chemicals	26	59	25.9	199.23
Pharmaceuticals	12	25	127.3	979.23
Electric Machinery	3	11	15.5	119.23
Nonelectric Machinery	1	5	8.6	66.15
Instruments	1	5	0.6	4.61
Transportation equipment	1	4	3.1	23.85
Petroleum	3	3	14.9	114.62
Food	1	2	1.1	8.46
Paper/pulp	2	2	0.3	2.31
Ceramics	0	2	1.0	7.69
Nonferrous metals	1	2	2.2	16.92
Rubber products	0	1	0.01	0.08
Total manufacturing	51	123	202.9	1,560.76
Retail services	4	15	2.9	22.31
Other services	0	5	4.0	30.77
Petroleum extraction	4	4	15.2	116.92
Total number of foreign R&D labs in Japan	59	137	211.4	1,626.15

SOURCE: Ministry of International Trade and Industry, *Results of the 24th Survey of the Trend of Foreign Affiliates in Japan* (Tokyo, 1990).

The great contribution of foreign-owned R&D to motor vehicles patenting in Japan, however, does not appear to be matched by high levels of foreign R&D investment or large numbers of foreign-owned facilities in

[19] See John Cantwell, "Global R&D and U.K. Competitiveness," in M. Casson, ed., *Global Research Strategy and International Competitiveness* (Oxford: Blackwell, 1991).

this industry within Japan. There are at least two possible explanations for this disparity. Cantwell's patent data are classified by the field of application of the patent, while the data presented above are classified by the "primary industry" of the investing firm. Cantwell's data thus treat a patent received on a ceramic engine part by a foreign-owned chemicals R&D laboratory in Japan as a "motor vehicles" patent, while the data in Table 3 classify this laboratory and its associated costs as a chemicals industry R&D facility. Alternatively, this disparity may reflect a failure by foreign motor vehicles firms to reward the significant technological contributions of their Japanese R&D facilities with higher levels of investment.

A recent contractor report to the National Science Foundation provides additional information (some of which appears to be inconsistent with the MITI data) on U.S. firms' R&D presence within Japan.[20] The NSF study found 71 U.S. firms with R&D operations in Japan, and received responses from 36 of these to a detailed questionnaire. The authors of the study note that their count of U.S.-owned R&D laboratories yielded an unexpectedly low total, a smaller number than was tabulated in the MITI study discussed above.[21] As in the MITI survey, the NSF study found that more than half of the firms responding to the survey were from the pharmaceuticals, chemicals, or petroleum industries, rather than the electronics sector.[22] The NSF study also obtained information on staffing patterns and motives for the establishment by U.S. firms of Japanese R&D facilities.

In general, despite the evidence cited above concerning the importance of Japan as a source of new industrial technology, the NSF study suggests that most U.S. firms continue to use Japanese R&D laboratories as instruments for improving or maintaining access to Japanese markets. This conclusion, which

[20] See National Science Foundation, *Survey of Direct U.S. Private Capital Investment in Research and Development Facilities in Japan* , contractor report for Science and Engineering indicators program prepared by Global Competitiveness Corporation and Technology International, Inc. (Washington, D.C.: 1991).

[21] "A major recent trend is the divestiture of established R&D operations in Japan by U.S. firms as a result of merger and acquisition (M&A) activity. Within the past four years, at least eleven U.S. firms with R&D facilities in Japan were either acquired by foreign companies or they sold off their R&D facilities...

"The divestiture of Japanese R&D facilities has been offset by a new wave. The latest group establishing R&D facilities has consisted primarily of software firms (CADEM, Lotus, MicroSoft, Nova Graphics) and medium-sized firms involved in electronics. In addition, a number of semiconductor and pharmaceutical firms are currently building R&D facilities or have indicated they will establish such facilities within the next two years.

"However, the number of U.S. companies with R&D facilities in Japan is substantially less than that believed at the onset of this study." Ibid., p. 3.

[22] "...17 of the 30 responses (57%) show primary R&D activity in the related fields of chemicals, plastics, petroleum refining, and drugs. We had anticipated that electronics and related fields would prove to represent the majority interest." Ibid., p. 8.

must be qualified by an acknowledgment of the low response rate to the NSF team's questionnaire, is based on the respondents' characterization of their motives for establishing a Japanese R&D laboratory:

> Objectives [in establishing a Japanese R&D lab] considered "very important" or "important" were: developing products for the Japanese market; to improve the quality and consumer acceptance of their products (by utilizing Japanese manufacturing technology); and entry into the Japanese R&D scene. Objectives considered "least important" were to establish a research base in the Far East; to increase the effectiveness of absorbing technology generated in Japan; and to qualify for Japanese government grants and loans for industrial R&D.[23]

U.S. firms also staffed their Japanese R&D facilities largely with Japanese scientists and engineers, rather than rotating personnel from other research facilities through their Japanese research facilities. This policy may make it more difficult to transfer Japanese-developed technologies to their U.S. or global operations.[24]

In other words, U.S. firms appear to be utilizing their Japanese R&D facilities to modify products for Japanese consumers and thereby improve their access to the growing Japanese market,[25] instead of using their Japanese R&D operations as part of a global technology development strategy. If the NSF study accurately characterizes U.S. firms' motives and R&D operations in Japan, it suggests that many U.S. managers have yet to modify their strategies to take into account the role of Japan as an important source of new technologies. This apparent lack of awareness may also be responsible for the relatively modest presence of U.S. electronics firms in Japan.

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[23] Ibid., p. 43.

[24] "Despite the recent publicity surrounding the potential technology transfer benefits from stationing U.S. R&D employees in Japan, this practice is very limited. Several respondents indicated that double taxation and fringe benefits makes employment of U.S. expatriates very expensive compared to hiring Japanese nationals...the major activity of the Japanese R&D staff was product development, followed in importance by applied research." Ibid., p. 6.

[25] The "market access" motive for offshore R&D has long been prominent in U.S. firms' foreign R&D investments. Mansfield and colleagues found that "in our sample, practically all of the firms doing R and D overseas say that the principal reason is to respond to special design needs of overseas markets. In their view, there are great advantages in doing R and D of this sort in close contact with the relevant overseas markets and manufacturing units of the firms." See Edwin Mansfield, David Teece, and A. Romeo, "Overseas Research and Development by U.S.-Based Firms," *Economica* 46, 1979, p. 188. Cantwell's analysis of trends in multinational firms' R&D investment behavior, however, emphasizes the recent growth in these enterprises' use of global R&D networks to support the growth of firm-specific technological capabilities drawn from a number of international and domestic sources. See Cantwell, op. Cit.

Japanese R&D Activity in the United States

Do Japanese firms adopt a different approach to their U.S. R&D? A survey of 100 Japanese subsidiaries in the United States, 10 of them acquired, showed that 45 percent conducted in-house R&D.[26] The managers surveyed frequently claimed that "the primary R&D objective of these subsidiary plants with in-house R&D was to expand present business and support present business," apparently through new product development. These results tell us little, however, about how these objectives are pursued. Respondents to the survey indicated that technology transferred from their Japanese parent company was overwhelmingly the most important source of technology. Little basic research is conducted in the United States by Japanese subsidiaries, although there are exceptions (e.g., NEC). Instead many Japanese firms use their U.S. research facilities to adapt technology to the U.S. market, in much the same fashion as U.S. firms historically have used their Japanese R&D facilities. In addition, of course, Japanese firms utilize their U.S. R&D facilities to monitor and assimilate U.S. technological and scientific advances.[27]

Sectoral differences are considerable. Japanese firms have established at least 70 electronics R&D facilities in the United States, according to data collected by Genther and Dalton and reproduced here as Table 4.[28] While many of these labs may be modifying Japanese technology for the U.S. market, there is little doubt that in the area of software development, Japanese firms are shoring up their historic weaknesses by hiring U.S. talent.

"Strategic Alliances" Between Japanese and Foreign Firms

Another important channel for foreign access to Japanese markets and technologies is through long-term agreements among firms that cover joint activities in R&D, product development, manufacturing, or marketing. Such "alliances" between U.S. and Japanese, U.S. and European, and Japanese and European firms have grown significantly in number during the past 20

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[26] Lois Peters, "Technology Strategies of Japanese Subsidiaries and Joint Ventures in the U.S.," Center for Science and Technology Policy, School of Management, Rensselaer Polytechnic Institute, 1991.

[27] Some evidence suggests that Japanese firms historically have been considerably more effective than U.S. firms in developing innovations based on sources of knowledge outside of the firms. If these differences are present as well in their management of foreign R&D, Japanese firms may be able to derive returns from their offshore R&D investments that exceed those of U.S. firms. See Mansfield, op. cit., footnote 10.

[28] See P.A. Genther and D. Dalton, "Japanese Affiliated Electronics Companies and U.S. Technological Development: 1990 Assessment," Office of Business Analysis, Economics and Statistics Administration, U.S. Department of Commerce, August 1991.

TABLE 4 Major R&D Facilities of Japanese Electronics Companies in the United States

Company	Location of Facility	R&D Activities in Electronics
Computers and Peripherals		
Asahi Optical	Pentax Technology Broomfield, CO	Scanners, laser printers (1985)
Epson	Epson Technology Center Santa Clara, CA	Personal computers (1988)
Fujitsu	Intellistor Inc. Longmont, CO	Disk storage devices (1987)
Hitachi	Waltham, MA	Workstation and Unix development (1989)
Konica	Konica High-Technology Laboratories Sunnyvale, CA	Data Storage(1984)
Matsushita	Panasonic Technology Palo Alto, CA	Computer document processing systems
Mitsubishi	Horizon Research Waltham, MA	Data processing (1985)
Mitsubishi	Mitsubishi Electric Research Laboratory Cambridge, MA	Superparallel computers (1991)
Nakamichi	Mountain View, CA	Disk drives (1987)
NEC	NEC Technologies Systems Laboratory Boxboro, MA	Workstations, laptops
Oki Electric	Advanced Technology Center	Laser printers, fax (1990)
Rohm	Rohm Research Corp. Boulder, CO	Printer heads (1990)
Sony	Intelligent Systems Research Laboratory San Jose, CA	Workstations (1988)
Sony	Data Storage Laboratory Boulder, CO	Erasable optical disks (1989)
Toshiba	Toshiba America Information Systems San Jose, CA	Laptops, personal computers
Computer Software		
Ascii	Media Technology Research Institute San Francisco, CA	Software and media (1990)
Canon	Costa Mesa, CA	Software, data processing (1990)
Fujitsu	Fujitsu Systems San Diego, CA	Software for POS, handheld computers, routing systems
Fujitsu	Information Systems San Jose, CA	Engineering related software
Fujitsu	Open Systems Solutions Emeryville, CA	Unix software (1991)
Hitachi	Hitachi Microsystems San Jose, CA	Software engineering, design and engineering support

Company	Location of Facility	R&D Activities in Electronics
Hitachi	Hitachi Software Engineering San Francisco, CA	Software (1991)
Hitachi	Hitachi Digital Graphics Sunnyvale, CA	CAD graphics, digitizers
Kobe Steel	Kobe Steel Research Laboratory Palo Alto, CA	Magnetic memories, artificial intelligence (1990)
Matsushita	Information Technology Laboratory Princeton, NJ	Computer graphics, document processing, software (1991)
Matsushita	Industrial Equipment Research Laboratory, Wood Dale, IL	Software for POS (1987)
NEC	NEC Research Institute Princeton, NJ	Al, parallel computing, machine learning (1990)
Ricoh	Ricoh Software Research Santa Clara, CA	Software (1988)
Seiko Instruments	San Jose, CA	Computer graphics
Sony	Sony Software Corp. New York. NY	Music and multimedia software, prepackaged software
Sony	Sony Microsystems San Jose, CA	Unix R&D (1990)
Sumitomo	Sumitomo Electric Santa Clara, CA	Software development (1991)
Zuken	Santa Clara, CA	Computer-aided design (1991)
Zuken	San Jose, CA	Computer-aided design (1993)
Semiconductors		
Canon	Canon Research Center Palo Alto, CA	Semiconductors (1990)
Fujitsu	Fujitsu Microelectronics San Jose, CA	Custom gate array design, SPARC
Fujitsu	Fujitsu Microelectronics San Jose, CA	Memories, logic and analog, ASIC
Fujitsu	Fujitsu Microelectronics Santa Clara, CA	Microwave (MIC) and lightwave integrated circuits (MMIC)
Hitachi	Brisbane, CA	Semiconductors (1989)
Hitachi	Farmington Hills, MI	Semiconductors for autos (1989)
Kawasaki Steel	Silicon Valley, CA	Semiconductors (1993)
Kobe Steel	Research Triangle Park, NC	GaAs and superconductive ceramics (1989)
Kobe Steel	San Jose, CA	Semiconductors
Matsushita	San Jose, CA	Semiconductors and software (1991)
Mitsubishi	Durham, NC	Semiconductors (1984)
NEC	NEC Electronics Natick, MA	Semiconductors (ASICs) (1987)

Company	Location of Facility	R&D Activities in Electronics
NEC	Mountain View, CA	VLSI (1986)
Oki Electric	Oki Semiconductor Sunnyvale, CA	Semiconductors (1989)
Ricoh	Ricoh California Research Center Menlo Park, CA	ASICs, CMOS (1989)
Rohm	Rohm Research Corp. San Jose, CA	Semiconductors (1990)
Sharp	Camas, WA	Semiconductors (1988)
Toshiba	Toshiba Electronic Components Sunnyvale, CA	Semiconductors (1984)
Telecommunication Equipment		
Applied Telesis	Seattle, WA	Data communications equipment (1989)
Fujitsu	Fujitsu Network Systems Raleigh, NC	Central office switching equipment (1987)
Fujitsu	Business Communication Systems Anaheim, CA	PBX equipment
Fujitsu	Telecommunications Research Center Richardson, TX	Telecommunications equipment
Fijitsu	Fujitsu Imaging Systems Danbury, CT	Fax machines
Hitachi	Hitachi Telecom Norcroff, GA	PBX, faxes (1987)
Matsushita	Applied Research Laboratory Burlington, NJ	Video broadcasting (1981)
Matsushita	Communications Systems Laboratory Secaucus, NJ	Digital cable TV systems
Matsushita	Research Triangle Park, NC	Satellite communications (1991)
NEC	Advanced Switching Laboratory Irving, TX	Central office switches (1989)
Oki Electric	Suwanee, GA	Telecommunications (1989)
Ricoh	San Jose, CA	Facsimile equipment (1979)
Sony	Sony Telecommunications Technology Center Paramus, NJ	Telecommunications
TDK	Components Engineering Torrance, CA	Microwave-related components

Company	Location of Facility	R&D Activities in Electronics
Toshiba	Toshiba America Information Systems Irvine, CA	PBX, cellular systems, fax (1985)
Optoelectronics		
Fujitsu	Microwave and Optoelectronics Division Santa Clara, CA	Microwave and lightwave semiconductors
Hoya Corp.	San Jose, CA	Optoelectronics (1989)
Hoya Corp.	Hoya Electronics San Jose, CA	Optoelectronics (1986)
Hoya Corp.	Hoya Optics Fremont, CA	Optical and laser glass (1973)
Hoya Corp.	Continuum Santa Clara, CA	Pulse laser beams
NTT	Photonic Integration Research Columbus, OH	Optoelectronics (1987)
Olympus	Torrance, CA	Optical and electronic products
Sumitomo	Research Triangle Park, NC	Fiber optics
Television		
Hitachi	Hitachi America Princeton, NJ	HDTV (1991)
Matsushita	Advanced TV-Video Laboratory Burlington, NJ	HDTV (1990)
Sony	Advanced Technology Center (AVIC) San Jose, CA	HDTV (1989)
Sony	Sony Engineering and Manufacturing San Diego, CA	TV components
Toshiba	Toshiba America Consumer Electronics Wayne, NJ	HDTV receivers (1990)
Semiconductor Materials and Equipment		
Hoya	Hoya Micro Mask Sunnyvale, CA	Photo masks
Hoya	Probe Technology Santa Clara, CA	Probe cards
Kyocera	San Diego, CA	Ceramics
Nikon	Nikon Precision Belmont, CA	Wafer steppers applications lab (1990)
ULVAC	Fremont, CA	Semiconductor equipment applications lab (1990)

Company	Location of Facility	R&D Activities in Electronics
Other Industries		
Canon	Newport News, VA	Copiers (1990)
Fuji Xerox	Palo Alto, CA	Communications networks for workstations (1992)
Matsushita	Speech Technology Laboratory Santa Barbara, CA	Speech recognition, information processing (1981)
Matsushita	Avionics Development Corp. Irvine, CA	In-flight audio, video systems for passengers (1990)
Nippon Columbia	Atlanta, GA	Multimedia R&D (1992)
Nippon Denso	Southfield, MI	Electronics (1987)
Sharp	Hycom, Inc. Irvine, CA	Flat panel displays (1989)
Sony	Sony Transcom Irvine, CA	In-flight audio, video systems
Toshiba	Toshiba America Medical (MRI) San Francisco, CA	CAT scanners, medical electronic equipment (1989)

SOURCE: Donald H. Dalton, U.S. Department of Commerce, July 1992.

years. Although international joint ventures have long been a mainstay of international business operations, the "alliances" of the past two decades focus more intensively on technology-intensive activities and industries, and frequently are concerned with product development or manufacture for a global, rather than a local, market. Most such alliances involving private firms are motivated by one or more of the following three factors: access to foreign markets; access to foreign technologies; and access to low-cost capital.

In industries like telecommunications equipment or commercial aircraft, the long-standing importance of governments as either purchasers or sources of influence over purchasers has made international collaborative ventures an important means of improving market access. In the semiconductor industry, bilateral trade disputes and the resulting "managed trade" agreements calling for improved market access also appear to have contributed to an increase in collaborative activity.[29] Political factors and market access restrictions, however, are not the only factors behind the recent growth in

[29] David Mowery, "Collaborative Ventures Between U.S. and Foreign Manufacturing Firms," *Research Policy* 18, 1989, pp. 19–32.

U.S.-Japan joint ventures. The sheer complexities of transferring and accessing external technologies through licenses, along with the growing technological prowess of Japanese firms, also have played an important role in the growth of U.S.-Japanese collaboration in industrial technology development.[30]

Tables 5-7 are drawn from a 1987 report by the Japanese Ministry of International Trade and Industry on Japanese participation in international research joint ventures. The report appears to have employed a fairly narrow, legalistic definition of a joint venture, in view of the differences between its tabulation and those drawn from other sources. Nevertheless, the tables yield important information on the growing technological linkages between foreign and Japanese firms. Table 5 displays trends in joint venture formation during 1982–1987, and together with Table 6, yields several interesting insights. Table 5 shows the acceleration in the number of newly formed international research joint ventures, which increased from 7 in 1982 to 36 in 1987.[31] Table 5 also suggests a high concentration of international joint ventures in the chemicals industry, which accounts for almost one-fifth of the total number of ventures formed during this period. Chemicals ranks second only to electronics in the number of joint ventures formed during 1982–1987. The importance of chemicals (which in this table includes pharmaceuticals) as a focus of international collaboration between U.S. and Japanese firms appears broadly consistent with the prominent role of pharmaceuticals and chemicals in the Japanese R&D investments of foreign firms discussed above.

Table 6 contains information on the nationality of the foreign participants in the international joint ventures covered in the MITI study and categorizes the joint ventures by technology field. U.S. firms dominate both the "conventional" and the "advanced" technology fields, accounting for 49 and 85 percent of the international joint ventures in the two categories respectively. U.S. dominance in computers and communications, biotechnology, integrated circuits, and factory and office automation (all of which are included in the "advanced" technology category) is even more pronounced. Table 7 disaggregates the international joint ventures by research activity. These data are consistent with the findings of other studies that international joint ventures among private firms rarely focus on basic

[30] See David J. Teece, "Transactions Cost Economics and the Multinational Enterprise: An Assessment," *Journal of Economic Behavior and Organization* , 7, 1986, pp. 21–45.

[31] Like many tabulations of trends in international joint venture activity, the MITI data in Tables 5-7 contain no information on terminated joint ventures. Since these undertakings are renowned for their high "mortality" rate, the MITI data may overstate somewhat the rate of growth in sustained collaborative activity. Any overstatement, however, almost certainly is more than offset by the effects of the MITI study's narrow definition of joint ventures.

or fundamental research.[32] Instead, consistent with the blend of technology access and market access motives that underpin many such undertakings, they are focused on product development and/or modification for global markets.[33]

TABLE 5 Formation of New International Research Joint Ventures Involving Japanese Firms, by Year and Industry, 1982–1987

Venture	1982	1983	1984	1985	1986	1987	Cumulative Total
Total	7	7	23	37	25	36	135
Manufacturing	6	7	19	29	18	30	109
Food	0	0	1	2	1	1	5
Textiles	0	0	0	2	0	3	5
Chemicals	1	1	7	7	4	4	24
Steel	1	1	4	0	0	2	8
General machinery	1	0	1	2	2	5	11
Electric machinery	3	4	4	9	6	6	32
Heavy electric machinery	3	1	0	4	3	0	11
Household appliances	0	1	3	2	2	0	8
Communication/ computer	0	1	1	2	1	3	8
Other electric machinery	0	1	0	1	0	3	5
Transport machinery	0	0	1	5	3	1	10
Instruments	0	1	1	1	0	3	6
Other manufacturing	0	0	0	1	2	5	8
Nonmanufacturing	1	0	4	8	7	6	26
Construction	0	0	1	1	0	1	3
Communications	0	0	1	2	1	0	4
Finance	0	0	2	3	1	2	8
Utilities	0	0	0	0	1	0	1
Other services	1	0	0	2	4	2	9

SOURCE: Ministry of International Trade and Industry, *Status Report on International Joint Research and Development of Japanese Private Enterprises* (Tokyo: 1987).

A recent study by the U.S. Department of Commerce examined a much broader array of linkages—what might be thought of as strategic alliances—between U.S. and Japanese firms, focusing on a "snapshot" of U.S.-Japan corporate linkages in six high technology industries during 1989–1990 (Table 8). Joint ventures account for less than 40 percent of the number of interfirm collaborative relationships in all of these industries, and in most instances are less frequent than are marketing collaborations

[32] David C. Mowery, op. cit.

[33] "Market-specified" R&D in Table 7 refers to incremental product modifications for new markets.

TABLE 6 Technology Fields of International Research Joint Ventures Involving Japanese Firms, 1982–87, by Field of Technology and Nationality of Foreign Firm

Venture by nation 1982-87	All Technology Fields	Conventional Technology	Advanced Technology	Communications/ Computers	Integrated Circuits	Factory and and Office Automation	Medical	Biotechnology	New Materials	Nuclear Power
United States	93	30	63	16	15	9	4	13	4	2
Canada	4	2	2	0	0	0	0	0	2	0
United Kingdom	13	8	5	2	0	1	0	2	0	0
Germany	9	7	2	0	1	0	0	1	0	0
France	7	6	1	0	0	1	0	0	0	0
Italy	5	5	0	0	0	0	0	0	0	0
Other	4	3	1	0	0	0	0	1	0	0
Total	135	61	74	18	16	11	4	17	6	2

NOTE: Advanced technologies includes the seven columns to the right of this category, respectively communications and computers; integrated circuits; factory and office automation; medical technologies; biotechnology; new materials; and nuclear power.

SOURCE: Ministry of International Trade and Industry, *Status Report on International Joint Research and Development of Japanese Private Enterprises* (Tokyo: 1987).

TABLE 7 International Research Joint Ventures Involving Japanese Firms, 1982–87, by Type of Research and Technology Field

Venture/ Type of Research	Conventional Technology	Advanced Technology	Communications/ Computers	Integrated Circuits	Factory and Office Automation	Medical	Biotechnology	New Materials	Nuclear Power
Basic research	2	1	0	0	0	0	1	0	0
Applied research	7	18	3	0	0	0	11	3	1
Product oriented	23	38	9	10	3	3	7	4	2
Market specified	28	23	6	7	6	1	2	1	0
Other	1	0	0	0	0	0	0	0	0
Unspecified	4	3	0	0	2	0	1	0	0
Total	65	83	18	17	11	4	22	8	3

SOURCE: Ministry of International Trade and Industry. *Status Report on International Joint Research and Development of Japanese Private Enterprises* (Tokyo: 1987).

and agreements.[34] The importance of the market access motive for many current interfirm alliances may be inferred from the substantial portion of collaborations in all of these industries that are focused on marketing or marketing and development of new products. Consistent with the MITI data on the research content of international joint ventures, very few of these U.S.-Japan joint ventures in Table 8 are concerned with research, as opposed to production and/or the development of products (an exception to this statement is the biotechnology industry).

Although the full impact of U.S.-Japanese collaboration on the competitiveness of U.S. firms will not be apparent for some time, the visible consequences of these collaborations thus far do not support the critical view of these ventures presented by Reich and Mankin.[35] Technology transfer within these ventures is more modest in scope and less uniformly "outbound" than some assessments assume. Just as U.S. industries vary in their trade balances in goods, the net inflow or outflow of technology through U.S.-Japan collaborations varies across industries. Requiring balance in technology transfer on an industry-by-industry basis makes no more sense than a requirement for such balance in goods trade. In a number of industries, including steel, automobiles, and portions of microelectronics, international collaboration can improve the international competitiveness of the U.S. participants. [36] In other industries, such as robotics, the competitiveness of U.S. systems engineering and software firms and the ability of large U.S. firms to offer a full line of factory automation hardware and software depend on access to foreign hardware through joint ventures and licensing. As we note below, however, the ability of U.S. firms to reap benefits from international collaboration ventures depends on the care with which these undertakings are organized and managed. In particular, U.S. firms participating in international joint ventures may need to strengthen their abilities to learn and absorb new technologies from their partners.

Many U.S.-Japan collaborative ventures involve the purchase by large Japanese firms of significant equity positions in small start-up firms. Do these foreign investments result in the export of critical technological assets that will strengthen Japanese competitors? Very little is known about the economic or technological importance of foreign acquisitions of U.S. high technology start-up firms. Although there are numerous uncertainties on

[34] Unfortunately, the lack of data on the size of the ventures in Table 8 means that the only basis for comparison of the "importance" of different types of collaborative activity is their number. Adjusting these data for the size of individual collaborative undertakings might yield different conclusions regarding the relative importance of various types of ventures.

[35] See R. Reich and E. Mankin, "Joint Ventures with Japan Give Away Our Future," *Harvard Business Review*, March–April, 1986.

[36] For a recent example, see the discussion of the alliance between Ford Motor Company and Mazda, "The Partners." *Business Week*, February 10, 1992, pp. 102–107.

TABLE 8 U.S.-Japan "Corporate Linkages," 1989–1990, in Selected High Technology Industries

U.S.-Japan Links 1989–1990	Aerospace	Computers	Software	Semiconductors	Semiconductor equipment	Biotechnology	Total
Marketing	19	36	38	33	11	22	159
Marketing/ development	0	2	3	1	1	0	7
Joint venture:	15	18	27	34	10	28	132
R&D/product	7	10	12	18	8	10	
Production	6	5	13	14	2	4	
Research	2	3	2	2	0	14	
Licensing	6	3	11	11	3	10	44
Technology exchange	0	2	0	10	0	2	14
Merger and acquisition	2	8	3	7	5	4	29
Direct investment	0	12	8	2	5	5	32
Consortia	1	1	0	0	0	1	3
Internal venture	0	0	0	4	2	4	10
Production	4	4	1	1	1	1	12
Other	0	1		2		1	4
Total	47	87	91	105	38	78	446

SOURCE: U.S. Department of Commerce, Japan Technology Program, *The Role of Corporate Linkages in U.S.-Japan Technology Transfer: 1991* (Washington, D.C.: NTIS, 1991).

this issue, the "leakage" of U.S. technology through such acquisitions may have only a slight economic impact. In many instances, start-up firms pursue international collaborative ventures because of their need for capital. Policies to reduce this supposed outflow of U.S. technology must address the availability of capital and/or the willingness of managers in established U.S. firms to support small start-up enterprises (overcoming resistance to technologies "not invented here"), rather than attempt to restrict collaboration.[37] Smaller firms' "export" of technology through international collaborative ventures rarely means that opportunities for exploitation of these technologies are lost to U.S. firms—in most cases, the U.S. partner in such a collaborative venture does not change its management or its location, and protection from other U.S. firms of its intellectual property is not airtight. The critical agents for the diffusion of these technologies (managers and employees of the small firm) remain in the United States, where they move to other firms, present the results of their research to domestic audiences, and otherwise act to disseminate much of the technology domestically. Indeed, the basis for such domestic high technology concentrations as Silicon Valley in California, Route 128 in Massachusetts, and North Carolina's Research Triangle is the tendency for critical technological assets (mainly people and specialized suppliers of goods and services) to remain regionally concentrated. If the enormous interregional flows of capital of the past 30 years have not diluted and diminished these regional concentrations within the United States, it seems unlikely that international capital flows will do so.

CONCLUSION

U.S. policymakers have yet to address the implications of change in the technological relationship between the United States and Japan. These changes pose a fundamental challenge to much current thinking in the executive branch and Congress, which now all too often proposes that Japanese access to U.S. science and technology be limited. Any restrictions on commercial technology transfer from U.S. universities or firms to Japanese entities, however, could provoke reciprocal restrictions that would harm U.S. competitiveness.

Paradoxically, the U.S. economy appears to have much more to lose and much less to gain by restricting foreign access to U.S. research and technology than at any previous point in the postwar era. The end of U.S. technological hegemony has weakened this nation's control over technology vis-à-vis foreign firms or individuals seeking access to U.S. Technologies,

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[37] See David J. Teece, "Foreign Investment and Technological Development in Silicon Valley," in D. McFetridge, ed., *Foreign Investment, Technology and Economic Growth* (University of Calgary Press. 1991), pp. 215–235.

In the current environment, U.S. firms stand to gain from continued improvements in their access to foreign markets, investment opportunities, and technologies. Achieving these improvements will be hampered if efforts are made to deny access to the U.S. research system.

The actions of many U.S. firms suggest that managers are beginning to pursue strategies designed to improve their access to the Japanese technological research system. Nonetheless, the evidence discussed above indicates that too many U.S. firms still view their Japanese R&D operations as oriented largely toward the domestic Japanese market, and are not working to exploit and transfer technologies from Japan into their global R&D networks. Japan's importance as a source of industrial technology means that U.S. firms must do more to gain access. This will require the expansion and establishment of corporate R&D facilities within Japan, as well as efforts to more closely link these facilities to corporate technology development strategies.

Similarly, the view that joint ventures with Japanese firms in research or product development give away our future must be qualified by an awareness of the potential and actual benefits of well-managed joint ventures for U.S. firms. U.S. managers nonetheless must proceed carefully in cooperating with an actual or potential competitor, and manage their technological and other assets strategically. In most cases, this requires that one maintain or strengthen independent technological and other capabilities, such as manufacturing or knowledge of markets and user needs, improving or sustaining the value of one's contributions to the joint venture. Successful participation in joint ventures requires that senior managers understand their firms' technological and other capabilities and incorporate them into strategic planning. Strategies designed to learn from the joint venture partner must be actively pursued, for ultimately the distribution of the benefits and costs from joint ventures in high technology will swing on how well each party is able to learn from the other.

The growing web of U.S.-Japanese technological linkages among private firms has and will continue to complicate any efforts by one or the other government to restrict access to its domestic research system. The effectiveness of SEMATECH's restrictions on foreign participation, for example, may be undercut by collaborative relationships between U.S. participants in the consortium and such Japanese semiconductor producers as Hitachi (which is working with Texas Instruments on advanced memory chips) and Toshiba (working with Motorola on memory and microprocessor chips). The development of international collaborative ventures among corporations is likely to frustrate attempts by governments to pursue "technological mercantilism"—attempting to restrict outflows of technology by governments in the same way that seventeenth-century European governments restricted outflows of specie. Such mercantilist policies provide powerful incentives for private firms to collaborate in R&D, marketing, and manufacture in order to improve their access to foreign markets.[38]

The growth of Japan's technological strengths has raised to high levels of the U.S. and Japanese governments (as well as increasing the level of conflict regarding it) the issue of access by foreign firms to the Japanese research system. This issue figured prominently, for example, in the 1988 negotiations over the renewal of the U.S.-Japanese agreement on scientific cooperation. The Japanese R&D system is difficult for foreign firms to penetrate for reasons that reflect the historic legacy of government policies, as well as differences in industry structure and in the structure of capital markets; these difficulties are not solely a result of current government policies. The complex origins of these structural differences in the organization of national R&D systems and in the ease with which foreigners can gain access to national R&D systems mean that government-to-government negotiations and agreements cannot address all of the causes and consequences of "asymmetrical access."

The structural differences between the U.S. and foreign research systems are such that a strict requirement of reciprocity in access to research facilities is either worthless or infeasible. Assurances by the Japanese government of complete access to Japanese universities, for example, may be of limited interest to U.S. firms, in view of the modest amount of world-class research performed by Japanese university researchers. A "results-oriented" reciprocity requirement that mandated that Japanese firms open their industrial research facilities to foreign researchers could impose a similar requirement on U.S. firms and is scarcely likely to elicit the support of U.S. firms.

Some evidence suggests that the structure of the U.S., Japanese, and Western European research systems may be converging somewhat. As and if the quality and amount of world-class research performed in Japanese universities and quasi-public "hybrid" institutions improve, for example, access to these facilities may become more attractive and important for informed U.S. and European firms. Reduction in the structural dissimilarities of these research systems could attenuate difficulties over reciprocal access, but any such process of institutional change and convergence is

[38] See David C. Mowery. "Public Policy Influence on the Formation of International Joint Ventures," *International Trade Journal*, vol. 6, 1991, pp. 29–62; and F. Chesnais, "Technical Cooperation Agreements Between Firms," *STI Review*, no. 4, 1988, pp. 51–119. Chesnais has noted the complementary relationship between relatively closed domestic research programs in the EC and the United States, such as JESSI and SEMATECH and international product development and technology exchange agreements in microelectronics: "...one finds a combination between *domestic* alliances in *pre-competitive* R&D (with all of the provisos attached to this notion), and a wide range of technology exchange and cross-licensing agreements among oligopolist rivals at the international level" (p. 95; emphasis in original).

likely to move so slowly that the issue of reciprocal access will remain very difficult for the foreseeable future. The serious impediments to U.S. acquisition of firms in other industrial economies, particularly Japan, are not exaggerated. They will continue to create serious tensions, exacerbating the effects of other structural differences in access to research projects and results, until they are reduced or circumvented.

The interdependent relationship between a scientifically strong U.S. research system and a technologically strong Japanese research system also raises complex issues of balancing national contributions and benefits to the global scientific and technological enterprise. The results of scientific research are increasingly mobile internationally and difficult to "appropriate" by the discoverer, a characterization that applies less accurately to the results of technology-oriented research. As a result, the possibility exists that the U.S. research system produces global "public goods," which can be exploited by (among others) Japanese firms for private profit. This characterization of scientific and technological research is at best a caricature, and understates the difficulties and costs of transferring and absorbing either type of information, but it captures an important difference between two research systems such as those of Japan and the United States.

The Japanese government has proposed several international scientific research projects (e.g., the Human Frontiers Science Program), in part as a means of expanding its contribution to global scientific research. The HFSP project has progressed quite slowly, however, and Japan's nonfinancial contributions to its advance are likely to remain modest. Significant Japanese participation in international scientific research projects in any but a financial role is likely to be hampered in the near term by the weakness of Japan's basic research capabilities in many areas. Japan's proposed Intelligent Manufacturing Systems (IMS) project, however, focuses on an area (advanced manufacturing process technologies) in which Japanese firms are in a leadership position and to which they could make significant contributions.[39] The IMS appears to contain considerable potential benefits for U.S. corporate participants.

Partly because U.S. government officials felt they had not been sufficiently consulted by the IMS project's Japanese sponsors, the U.S. government was initially reluctant to support the IMS proposal. In addition to their concerns over a perceived lack of advance consultation, some U.S. officials felt that U.S. firms would contribute more to the undertaking than they would receive, transferring U.S. technology to Japanese firms. This concern appears to be misplaced, for several reasons. It is based on an

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[39] See George R. Heaton, *International R&D Cooperation: Lessons from the Intelligent Manufacturing Systems Proposal*, Manufacturing Forum Discussion Paper #2 (Washington, D.C.: National Academy Press, 1991).

outdated assessment of U.S. and Japanese technological strengths in manufacturing. This approach also attempts to substitute the technological judgments of U.S. policymakers for those of corporate managers. Finally, opposition to U.S. participation in the IMS may reinforce the already distressing tendencies of U.S. managers to ignore external sources of industrial technology. The ambivalent response of the U.S. government to this Japanese proposal for international collaboration on technology-oriented research is unfortunate, and suggests the need for a recognition by U.S. policymakers of Japan's technological capabilities and a more realistic appraisal of the costs and benefits of U.S. participation in international technology development programs.

Intellectual property rights is another area of U.S.-Japan tension and negotiations that may now assume a very different role in this bilateral economic relationship. During the past decade, U.S. pressure has led the government of Japan to improve the protection offered to foreign firms' intellectual property, and U.S. firms such as Texas Instruments have begun to reap significant royalty payments for such key patents as that covering the integrated circuit. Simultaneously, the executive branch and Congress have taken a number of steps to strengthen the domestic protection of intellectual property rights in the United States. As was noted above, however, Japan now is increasingly a technology exporter and is a major patentor in the United States. Stronger international and domestic intellectual property rights protection thus may raise the costs to some U.S. firms of access to the increasingly important flow of technology from Japanese sources.[40]

As the example of intellectual property suggests, the effectiveness and value of specific technology policy initiatives depend critically on the level of technological development within an economy, both absolutely and relative to other economies. The Japanese government policies that are asserted to have contributed to the technological transformation of that economy now have many admirers and advocates within the United States. Even as some U.S. observers recommend emulation of Japanese research policies and institutions, however, a search is under way within Japan for new institutions to support the indigenous basic research believed necessary to underpin commercial innovation. Japanese cooperative research policies, for example, historically supported the diffusion and utilization of technological and scientific knowledge that was derived from external sources, and supported Japanese firms' efforts to "catch up" with global technology leaders. Within Japan, however, cooperative research rarely served to advance the scientific or technological frontier, a purpose for which it is often

[40] Some Japanese firms already are aggressively pursuing infringement actions against South Korean firms. See S.K. Yoder, "Hitachi Reaches Patent Accord with Samsung," *Wall Street Journal*, April 5, 1989, p. B3.

promoted in the United States. Moreover, uncritical imitation of this and other technology policies associated with the period of "catch-up" in the Japanese economy overlooks considerable evidence suggesting that Japanese policymakers are now considering policies, such as public funding of basic research, that have long been central features of the U.S. national research system.

Above all, it is important to recognize that the current complexities in U.S.-Japanese economic and technological relationships are a legacy of successful domestic and international policies. Japan's postwar rise to technological leadership is attributable in part to U.S. policies that assisted Japanese national security and economic reconstruction. U.S. and Japanese citizens alike should be proud of this remarkable accomplishment. Nonetheless, adjustment by policymakers and managers in both the United States and Japan to new technological realities will require fresh thinking on both sides of the Pacific. Failure to adjust to the new environment will result in missed opportunities and unnecessary friction.

Implications of Japan's "Soft Crisis": Forcing New Directions for Japanese Electronics Companies

WILLIAM F. FINAN AND CARL WILLIAMS

INTRODUCTION

There is a clear need in the United States to understand the implications of Japanese successes in scientific and technical fields. But the focus of this paper will be on a different facet of Japanese technology development: how do Japanese firms respond when they are unable to maintain an adequate technical development program in a critical technical field? This concern is very different from several decades ago when the concern in Japan was to overtake the Western lead in critical technologies. In examining this problem in Japan, we are in some sense looking at a mirror image of the problem that has surfaced in the United States, namely, how most effectively to allocate scarce resources to key areas in order to maintain competitiveness in critical technologies.

Japan is currently facing a situation in which there is a growing relative scarcity of engineering talent at all levels as demand outstrips supply. In other words, there are simply not enough indigenous resources (i.e., new engineering graduates and university-based advanced research programs) to fill the expected future demand for technical expertise inside Japan. Already, Japanese high technology companies are encountering strategic technical fields where they cannot develop sufficient indigenous talent in a reasonable time frame. This prevents or delays them from mounting an effective autonomous development effort. As these delays and shortcomings become more common, we believe the outcome will be a significant restructuring of Japanese interaction with the U.S. scientific and engineering community.

This state of affairs cuts across the spectrum of engineering disciplines to a lesser or greater extent. However, the shortage of skilled technical labor is particularly acute in the field of software engineering. In fact, the term "soft crisis" has been used to refer to the lack of adequate software engineering talent in Japan.[1] Therefore, we will begin by examining the source of the labor shortage problem in software engineering fields, and explanations for the inability of Japanese educational institutions to respond to this problem.

In order to illustrate possible solutions to this "soft crisis", this paper will focus on a subfield of the software engineering industry known as integrated circuit computer-aided design (IC CAD).[2] It is a field related to the design of complex ICs, and therefore it is a field of critical importance to IC firms as design complexity of ICs has increased—an importance that will further increase in the future.[3]

We will then outline various measures taken to address this shortage, and draw some implications for the United States of these actions taken by Japanese firms.

PROBLEMS CONFRONTING THE JAPANESE SOFTWARE ENGINEERING INDUSTRY

The problems confronting the Japanese software engineering industry can be summarized as follows:

- The "soft crisis" is a function of the explosion in the growth of the Japanese software industry in bumping up against a fairly inelastic supply of software engineers.
- Japanese educational institutions have proved to be inadequate to the task of increasing the supply of software engineers. They continue to act as a bottleneck because the Japanese universities are slow to reorient their programs to emerging fields—if they are able to do so at all.

The pressures of the "soft crisis," together with the inadequate response of Japanese universities, will force the Japanese companies to resort increasingly

[1] The term "soft crisis" comes from the Japanese abbreviation of "software crisis." Professor Shirakawa of Osaka University first coined this term in 1988.

[2] Based on the value of sales of independent IC CAD tool vendors, the IC CAD tool business is relatively small, though expanding rapidly. Worldwide sales of all major IC CAD vendors in 1989 were estimated to be about $170 million. By comparison, the worldwide revenues of semiconductor firms in 1991 totaled about $50 billion and are expected to expand at a 10–15 percent annual compound rate of growth.

[3] See William F. Finan, and Jeffrey Frey, *Development of Integrated Circuit Computer Aided Design Tools in Japan*, Report to the Semiconductor Research Corporation, July 1991. This paper draws heavily on the field interviews they conducted.

to "nonconventional" means to solve the software engineering shortage. In order to outline what form these nonconventional means are taking on, we will describe how Japanese firms are dealing with the shortage in the IC CAD field.

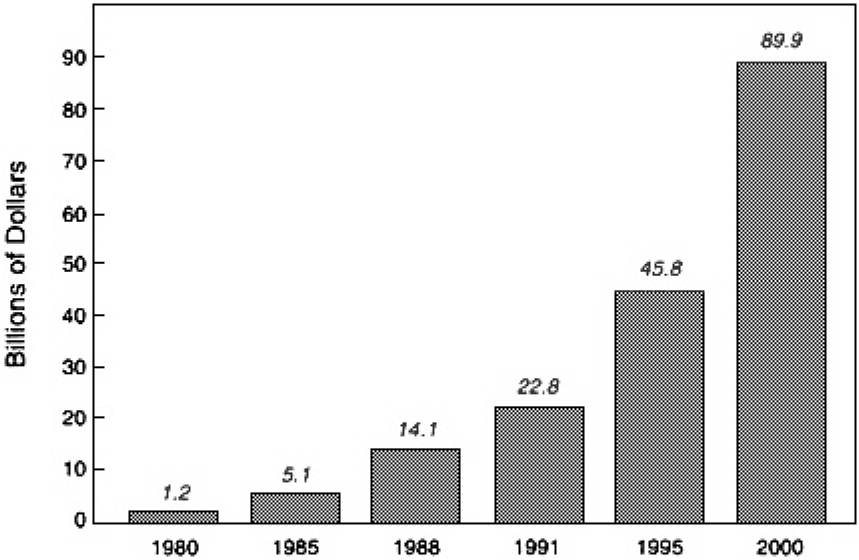

Figure 1 Japanese market for software-related products. Source: Japan Information Service Industry Association.

Description of the "Soft Crisis"

The software market in Japan is expected to increase substantially in the next few years. The programming services and software products market, of which CAD is a subset, amounted to approximately $14 billion in 1988. Sales are expected to explode to $90 billion by the year 2000 in constant 1988 exchange rates[4] (see Figure 1).

Japanese firms are encountering difficulties in recruiting the qualified technical labor necessary to meet this explosion in the software industry. The bulk of technical labor is recruited from the available pool of college and technical school talent. However, for a variety of systemic and exogenous factors, this pool is currently inadequate to meet the demand for

[4] Japan Information Service Industry Association (JISA), *Information Service Industry in Japan: Growth and Prospect*, (Tokyo: 1990). JISA is comprised of over 500 member and 100 supporting Japanese companies.

technical labor and, further, is projected to decline relatively over the next decade. One striking illustration of the acuteness of this shortage of graduates is in the IC CAD field. It is estimated that the United States has at least a 5 to 1 and perhaps as much as a 10 to 1 advantage in terms of qualified CAD engineering personnel. [5] Other strategic areas that are tied to software engineering are experiencing a similar magnitude of shortage.

Shortcomings of the Japanese Educational System

Generally, new hires for skilled technical positions by Japanese firms come from the annual crop of college graduates. Because of the "lifetime employment" tradition, there has historically been relatively little recruitment of midcareer professionals, a practice termed "lateral hiring." Therefore, Japanese companies are directly affected by the profile of the Japanese college population.

There are really two facets to the problem of the adequacy of supply of software engineers. First, the evidence suggests that, increasingly, Japanese students are not interested in entering science-and engineering-related programs. At the same time, the Japanese universities are not responding to the changing requirements of emerging technical fields. Committed to programs that relate to older technical fields, they have been slow to increase their offerings in newer technical fields. Combined, the reduced supply and the inability to shift resources towards a software-related teaching curriculum leave Japanese companies in a real bind.

As long as the college-age population was expanding and, in particular, those fields of study important to engineering were expanding as a fraction of the total, there was no real difficulty with respect to sufficient engineering labor. However, the population of college-age Japanese is currently peaking. In the future, not only will the number of science and engineering graduates decline as the general student population declines over the coming years, but career preferences are serving to exaggerate this decline relative to the overall graduate population. Evidence reveals that more and more Japanese university students in the major Japanese universities are gravitating toward the disciplines of business, law, and finance.

A recent study by the Japanese National Institute of Science and Technology Policy (NISTEP) examined this phenomenon. NISTEP projected the number of applicants to science and engineering programs through the year 2000. Two cases were examined.[6] In the first case, the ratio of applicants to science/engineering programs to the overall college-age population

[5] Finan and Frey, op. cit., p. 42.

was assumed to remain the same as the ratio observed in 1989. In the second case, the rate of decrease of the number of applicants, as experienced over the period 1987–1989, was assumed to continue. In both cases the trend for science/engineering applicants is down over the next 10 years (see Figure 2). However, estimates based upon the second case show a more drastic decline. In this case, by 1995, the overall number of applicants may not even be enough to match the actual enrollment levels of 1989. By the year 2000, total *applicants* to science and engineering programs could drop to approximately 55,000. This is dramatically below the level of 65,000 *enrolled* science and engineering students in 1989, a decade before.

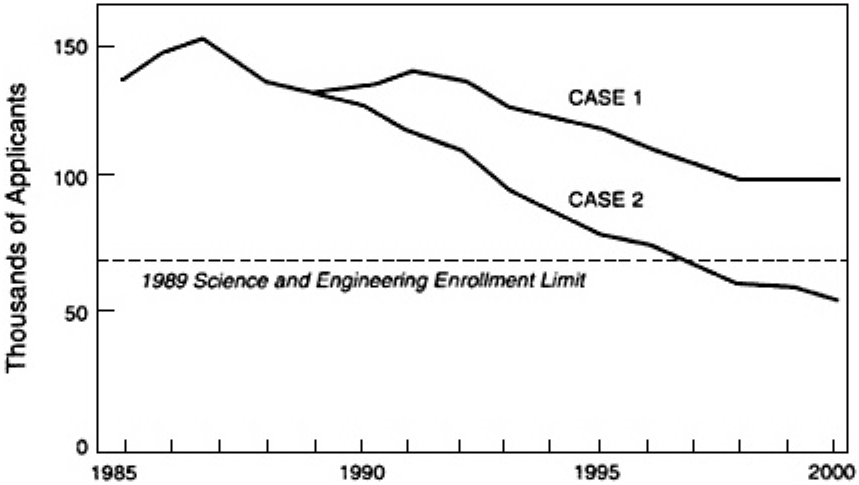

Figure 2 Scenarios for science and engineering program application trends. Note: Case 1—The ratio of applicants to science/engineering programs to the overall student population remains the same as the ratio observed in 1989. Case 2—The rate of decrease experienced over the period 1987–1989 is assumed to continue. Source: National Institute for Science and Technology Policy.

At the same time that the scientific and engineering talent pool is declining, institutional rigidities in the Japanese educational system inhibit the supply of trained recruits for Japanese firms. In particular, there are usually quotas on the number of students that are admitted to the various disciplinary fields. These quotas are a result of decisions made by the Ministry of Education and the entrenched engineering faculty in the leading universities. In fact, in an attempt to bypass these bottlenecks, the Ministry of International Trade and Industry (MITI) has instituted measures to promote the establishment of "information colleges," with the aim of dramatically

[6] After the National Institute of Science and Technology Policy, *NISTEP Report No. 12*, (draft translation), August 1990, p. 20–21.

increasing the numbers of trained software engineers. However, this approach has not made a substantial impact on the overall shortage problem.

These estimates of the growing software engineer shortage strongly suggest that Japanese high technology companies—which require an ever increasing number of science and engineering graduates—will face severe problems in the future.

RESPONSES OF JAPANESE FIRMS TO THE SOFT CRISIS

In order to address the growing shortage of software engineers, Japanese companies will be forced to resort to nonconventional means—that is, nonconventional for Japanese firms. To illustrate this, we will summarize how Japanese companies in the IC CAD field are addressing the shortage.[7] Some of these solutions are rather innovative and serve to indicate practices that may be adopted by broader segments of Japanese industry in the future.

First of all, there is a clear trend in the IC CAD field to resort to nontraditional sources of CAD software talent. In the past, Japanese companies would usually shift internal labor resources to key sectors, utilizing well-developed internal training programs. This approach to personnel development will continue to predominate in the face of the software shortage. However, Japanese firms are beginning to realize that they must look to labor resources outside of the typical pool of Japanese males; that is, there will be increased hiring of women and foreigners. Also, there will likely be increased raiding of competitors ("lateral hires") for scarce talent, a tactic that has rarely been used in the "lifetime employment" culture of corporate Japan.[8] Both of these developments suggest that, as the shortage of software engineers becomes more acute in Japan in the future, these trends will be reinforced.

Another response by Japanese firms to the pressures of the engineering shortage is to open research facilities offshore. A number of Japanese firms have begun investing in software research by setting up laboratories overseas and hiring top research talent away from native firms. As opposed to earlier research labs, these facilities will be more than simply listening posts or showcase facilities. They are specifically intended to expand the

[7] IC CAD is a technical field where Japanese managers believe they are lagging behind the state of technical developments in the United States (see Figure 3). This competitive environment is forcing Japanese firms to adopt a more flexible set of policies towards technical development in this area. Because of the shortage of talented software engineers and the lack of a strong, sophisticated CAD research base in the academic community, Japanese CAD firms are compelled to be heavily dependent upon outside firms as a source of CAD tools.

[8] Finan and Frey, op. cit., pp. 51–52.

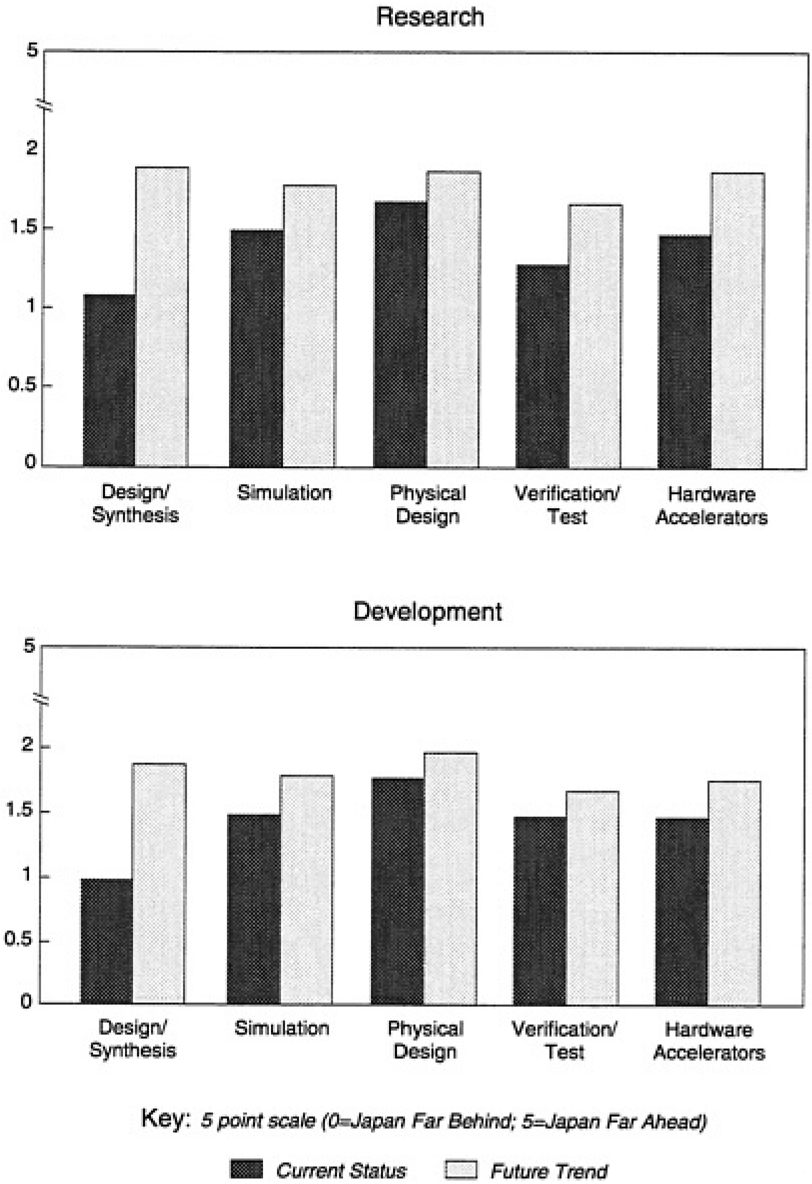

Figure 3 Comparison of CAD in Japan relative to the United States. Note: 5 point scale (0 = Japan far behind; 5 = Japan far ahead). Source: Semiconductor Research Corporation questionnaire.

engineering pool, including CAD design, to which the Japanese companies have access.[9]

IMPLICATIONS FOR THE UNITED STATES

The "soft crisis" and the changing Japanese strategies to deal with it have implications for U.S. science and technology policy vis-à-vis Japan. To list a few:

1. Japanese firms will be actively bidding to attract scarce engineering talent in the United States. How successful this thrust will be depends, in part, on the success that Japanese firms have in managing highly skilled engineering talent. Japanese car firms who have successfully operated design centers in the United States demonstrate that it is feasible to do this.
2. Japanese firms will be forced to accept a certain amount of dependence upon foreign sources of key technology in certain areas. Therefore, Japanese firms will seek to ensure that, in those areas where they have to remain strategically reliant on U.S. (or European) firms for critical technologies, those technologies will not become bottlenecked—that is, that they will continue to have unfettered access at reasonable prices to the necessary technology.
3. Traditional Japanese corporate culture will undergo changes as Japanese firms resort to such nonconventional practices as lateral hiring. This will result in "spin-off" bonuses for U.S. firms; namely, U.S. firms will have greater access to the Japanese engineering establishment through greater ability to laterally hire highly skilled Japanese engineers into U.S. laboratories and firms located in Japan.

There are further implications for U.S. firms that go beyond recruiting issues. An understanding of conditions surrounding problems facing Japanese competitors, such as the soft crisis, will contribute to the ability of U.S. firms to take advantage of the shifting structures of Japanese corporate culture as Japanese firms respond to these problems. U.S. companies can reap benefits from changes in corporate culture in Japan; adoption of flexible policies will help ensure the realization of these benefits.

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[9] Among the Japanese firms who have taken this step are NEC, Matsushita, Canon, and Mitsubishi; see the *New York Times*, November 11, 1990.

III

THE FUTURE OF COMPETITION

Japan's Unique Capability to Innovate: Technology Fusion and its International Implications

FUMIO KODAMA

JAPAN'S UNIQUE INNOVATION CAPABILITY

In 1975, the Japanese created a new word "mechatronics" by combining the two words mechanics and electronics. Essentially it implies the following two categories of products. (1) The marriage of electronic technology to mechanical technology resulted in the birth of a more sophisticated range of technological products. Typical examples are NC (numerically controlled) machine tools and industrial robots. (2) Products in which a part, or the whole, of a standard mechanical product was superseded by electronics make up the second category. Typical examples are digital clocks and electronic calculators.

In the machine tool case, the diffusion rate of mechatronics technology can be measured by the ratio of the numerically controlled machine tools to the total production of machine tools. A marked increase in the diffusion rate, in fact, occurred in 1975. Since then, diffusion has been quite rapid in this industry.

Mechatronics: A Key to Japan's Industrial Strength in the Past

Let us try to measure the diffusion of mechatronics technology in various types of machinery. A "mechatronized machine" is defined as a machine with computer control. The diffusion rate can be measured by the ratio of the mechatronized machines to the total production of machines. Those categories of machinery in which the diffusion rate of mechatronics is above 30 percent are industrial robots, machine tools, bending machines, and printing and bookbinding machinery. Those categories of machines that are not yet widely mechatronized are sewing machines, woodworking machinery, plastics-processing machinery, and food-processing machines.

TABLE 1 Mechatronics Ratio and Growth Rate

Category of Machinery	Percentage of Mechatronized Machines	Growth of Production 1983/1977
Industrial robots	80	10.67
Machine tools	60	2.52
Bending machinery	30	7.00
Printing and bookbinding machinery	30	2.44
Forging machinery	20	0.76
Sewing machines	20	0.99
Woodworking machinery	10	1.35
Plastics machinery	10	2.18
Food-processing machinery	3	1.71

SOURCE: MITI, *Vision for Industrial Machinery* (Tokyo: 1984), p. 200.

Moreover, we can observe a significant difference in the growth of production between these two categories of machinery, as shown in Table 1. As the table clearly shows, the group with a diffusion rate of mechatronics higher than 30 percent has a higher growth rate. On the other hand, the group with diffusion of less than 30 percent has grown more slowly. Thus there seems to be a positive correlation between the diffusion rate and growth. This indicates the possibility that the group whose growth is stagnant may regain a growth momentum with the introduction of mechatronics technology.

Optoelectronics: An Emerging Capability

In the 1980s, optoelectronics, a marriage of electronics and optics, has been yielding important commercial products such as optical fiber communications systems. It united the electron with the ephemeral photon, the particle of light, to attain greater efficiency in data processing and transmission than electronics can achieve by itself. It is drastically revolutionizing the communications system and is widely expected to form the next generation of information-based technology.

In 1986, *Fortune* magazine asked 10 scholars, business executives, government officials, and foundation leaders in each field to rank the state of research and development in the United States, Japan, Western Europe, and the USSR on a scale of 1 to 10. The focus of the study were the following four technological fields: (1) computers, chips, and factory automation;

(2) life sciences; (3) advanced materials; and (4) optoelectronics, as shown in Table 2.

TABLE 2 Results of the Fortune Scoreboard

Technical Field	United States	Japan	West Europe	USSR
Computers, chips, factory automation	9.9	7.3	4.4	1.5
Life sciences	8.9	5.7	4.9	1.3
Advanced materials	7.7	6.3	6.0	3.8
Optoelectronics	7.8	9.5	5.7	3.6

SOURCE: Gene Bylinsky, "The High Tech Race: Who's Ahead?" *Fortune*, October 1986, pp. 18–36.

As can be seen in the Table 2, there is one field in which the United States was not rated number one: optoelectronics. The magazine reported that everyone conceded that the Japanese lead the world in this important new technology, which was originally developed in the United States. In the *Fortune* piece, an expert commented that the Japanese lead is very considerable, and there is little evidence that anything we are doing in this country will close the gap in the near future.

Characterization: Technology Fusion

Conventional wisdom holds that technical innovation is achieved by breaking through the boundaries of existing technology. With regard to recent innovations in new fields such as mechatronics and optoelectronics, however, it would be more appropriate to view innovation as fusing different types of technology rather than as technical breakthroughs.

Therefore, we might better say that the mechatronics revolution is generated by the fusing of mechanical technology with electronic and materials technologies, and that the optoelectronics revolution is generated by the fusing of glass technology with cable and electronic device technologies. As the names mechatronics and optoelectronics imply, "fusion" means more than the summation and combination of different technologies, and implies an arithmetic in which one plus one make more than two.

The fusion of technologies goes beyond mere combination. Fusion is more than complementarities,[1] because it creates a new market and new growth opportunities for each participant in the innovation process. Fusion goes beyond the cumulation of small improvements, because it blends incremental improvements from several (often previously separate) fields to create a product endowed with some extra ingredient not found elsewhere in the market. It also goes beyond interindustry relationships, because different innovations in different industries progressed in parallel, taking the form of joint research.

NEW OPPORTUNITIES FOR TECHNOLOGY FUSION

Expected Technological Advances

Roughly every five years, Japan's Ministry of International Trade and Industry draws up a list of major fields of technology. At the last such meeting, which I had the good fortune to chair, scientists and engineers representing seven technological fields gathered together to draft the list. This time, however, we tried a somewhat different approach.

We asked the participants from each field to list those fields, outside their own, from which they are most eagerly anticipating new advances. We asked these questions of scientists and engineers who are working in corporate R&D and planning, in terms of their expectations in the short term (0–5 years) and in the long term (5–10 years).

The seven technical fields consisted of new materials, biotechnology, electronics (hardware), information processing (software), energy, aerospace, and construction/transportation; 70 scientists and engineers were sampled for each technical field. Thus we sent the questionnaire to 490 people in 231 companies. A total of 149 responses were obtained, which represents a return ratio of 30 percent. The most active response came from information processing: its return ratio was 42 percent, followed by energy (33 percent). This reflects the fact that advances in these technical fields heavily depend upon advances in other technical fields.

Table 3 summarizes the results of our survey for the short term (0–5 years). The second row from the bottom gives each field's maximum possible number of responses (i.e., the total number of respondents minus the respondents in the field itself). Expectations are reported in two rows, the third row from the bottom recording the number of respondents in other fields who indicated high expectations for developments in that field, and the bottom row expressing this number as a percentage of the maximum possible number of respondents.

According to these scores and percentages, within the next five years the greatest expectations are held for electronics (i.e., as many as 94 respondents in other fields, or 72 percent of all possible respondents, answered that they anticipate advances in that field). This is followed by new materials (85 points) and then by information processing (72 points). However,

[1] N. Rosenberg, *Inside the Black Box: Technology and Economics* (Cambridge: Cambridge University Press, 1983).

relatively little is anticipated from the fields of biotechnology, aerospace, energy, and construction.

TABLE 3 Expectations for Development Across Technological Fields

	Expectations for						
Expectations by	New Materials	Biotech-nology	Elec-tronics	Infor-mation	Energy	Aero-space	Construc-tion
New materials	—	2	15	10	11	9	2
Biotechnology	12	—	12	14	0	1	1
Electronics	16	1	—	13	4	6	2
Information processing	11	3	29	—	2	2	1
Energy	19	2	18	14	—	3	6
Aerospace	13	3	11	9	4	—	2
Construction/ transportation	14	3	9	12	6	2	—
Total (A)	85	14	94	72	27	23	14
No. of possible respondents (B)	128	130	130	119	126	131	130
(A/B) (%)	66	11	72	61	21	16	11

SOURCE: Japan Society for the Promotion of Machinery Industry, "Survey on the Interaction Among Important Industrial Technologies" (in Japanese), Tokyo, May 1990.

The high marks for electronics do not need any explanation because in the last decade we have observed radical progress in microelectronics and can expect this trend to continue. The high score for information processing reflects the fact that, like genetic engineering, it is expected to provide important tools for research and analysis. Expectations vis-à-vis biotechnology remain low, however, as this area has yet to move much beyond the conceptual stage. It also reflects the disappointment of Japanese industry in the results delivered by biotechnology thus far.

The low expectations regarding aerospace and energy, however, merit particular attention. It is widely known that state-sponsored aerospace and energy projects, many of which are military related, have produced numerous breakthroughs in new materials, electronics, and software, in the form of spin-offs. The low expectations for this field, however, seem to indicate that the development of new materials and computers is generally no longer expected to follow these conventional mechanisms. New materials and computers are now expected to be developed in direct response to specific technological needs, rather than emerging in a roundabout way from defense-related projects. In the area of software, for example, it is interesting to note that current work on a system to regulate the electric power supply of greater Tokyo's 30 million residents is far larger than most defense systems.

TABLE 4 Expectation of Advances in Each Technological Area

	Possible No. of Responses	Short Term (0–5 years)		Long Term (5–10 years)	
	A	B	B/A (%)	C	C/A (%)
New materials	128	85	66	94	73
Biotechnology	130	14	11	62	48
Electronics	130	94	72	78	60
Information	119	72	61	68	57
Energy	126	27	21	45	36
Aerospace	131	23	16	38	29
Construction	130	14	11	16	12

SOURCE: Japan Society for the Promotion of Machinery Industry, "Survey on the Interaction Among Important Industrial Technologies" (in Japanese), Tokyo, May 1990.

Table 4 summarizes the results for the short term (0–5 years) and the long term (5–10 years), so that the shift from the short to the long term can be seen. In the longer term, great expectations are held for new materials (i.e., 94 positive responses, or 73 percent of all possible responses). Expectations for electronics fall to second place in the longer term: 78 points, or 60 percent. This reflects the widely held view that the major breakthrough will be affected only by the development of new materials, not through the application of electronics.

It is hoped that, in the future, biological processes will come to replace physical and chemical processes in various fields of manufacturing. This is reflected in the increased expectations for biotechnology in the long-term view (5–10 years). Its score increases from 14 points (11 percent) in the short term to 62 points (48 percent) in the long term.

New Materials: Designed Materials

Discussions about high technology industries often center around electronics. As far as the importance of materials is concerned, however, a growing consensus seems to be emerging among experts in various fields from various countries.

Tadahiro Sekimoto, president of NEC Corporation, has pointed out that developments in the electronics industry depend on developments in materials research. Along the same lines, Professor Hiroshi Inose, winner of the

Marconi Award for his work in digital communications, claims that the focus of technological development once shifted from systems to devices, and now it has shifted again to materials. In the United States, Ralph E. Gomory, formerly senior vice president and chief scientist at IBM, has made the point that every single step in computing has depended on solving one materials problem after another. As these comments indicate, expectations regarding advances in materials technology are greater now than ever before. Materials have clearly played an important role throughout history. How, then, are today's expectations of materials technology different from those of the past?

Throughout the history of civilization, materials gave their names to whole epochs: the Stone Age, the Bronze Age, the Iron Age. However, until recently the materials involved have been mostly nature's gifts or simple improvements on them. But now we are standing on the threshold of a new age of *man-made* materials, because today scientists can tailor the basic structures and properties of materials to suit their needs. Companies that lead in inventing and producing these ingredients of tomorrow will be in a strong position to dominate many high technology industries.

It is widely believed in Japan that the country is entering the age of fourth-generation materials. The first-generation materials are stone and wood, whose use entails only transforming natural resources. The second-generation materials are copper and iron, which become usable by extracting components from naturally available materials. A typical example of third-generation materials is plastics, which are not available in nature but are made by synthesizing them artificially. Fourth-generation materials will be designed according to usage by controlling the behavior of atoms and electrons in the materials, in the same manner in which we design equipment and systems.

Increasing expectations regarding new, directly applicable materials technology reflect, at least in part, a dramatic change in the nature of technological innovation in the materials field. The terms "materials design" and "custom materials" have also recently entered the scientific lexicon. This means that molecular structures can now be artificially manipulated to produce specific materials for specific uses.

Therefore, I would argue that the essence of the new materials revolution is the technology fusion between two industries, fabrication and materials, which had never been realized before. If this is the case, it can no longer be taken for granted that the Japanese materials industries are much weaker than the fabrication industries. In fact, an early indication can be found in the results of the *Fortune* scoreboard in Table 2, which revealed that the ratio of Japan/U.S. scores was as close as 0.82 in advanced materials, compared to 0.74 in computers and 0.64 in life sciences.

An interesting implication derived from the findings that the new materials revolution is a product of technology fusion might be that the pattern of this revolution will not follow the conventional pattern of a materials revolution. The main actor in this revolution will not necessarily be the materials industry, but might be the fabrication industry, the customer for materials. We can find early indications of this possibility in the recent Japanese development of optical fiber technology, in which NTT, the customer for optical fiber, developed the manufacturing technology.

Biotechnology: Rational Drug Design

The concept of "technology fusion" can be extended further beyond physical sciences and chemistry. Through the emergence of biotechnology, the trend toward technology fusion is becoming obvious even outside physical and chemical sciences. The concept that corresponds to "materials design," is known as "rational drug design" in biotechnology. The traditional way of discovering pharmaceuticals was to screen thousands of chemicals in a hit-or-miss search. This is inefficient and wastes time.[2]

Instead of hit-or-miss screening, the new breed of drug designers now uses biotechnology to help them work backward from what biologists know about a disease and how the body fights it. It is essentially the long-awaited combination of biotechnology and chemistry: a technology fusion that promises to streamline and enhance drug development and reshape the biotechnology and pharmaceutical industries.

These drugs should be far more effective against disease and have fewer side effects than current drugs. Dozens of companies that are zeroing in on drugs to fight nervous system disorders have used biotechnology to unravel brain function. They will likely use chemical synthesis to create their drugs.

Although the development of biotechnology is more targeted toward producing pharmaceuticals in the United States, the Japanese think of it in a broader area of application. The concept of biochemistry had long been taken for granted in Japan, because of its long tradition of fermentation technology. The situation is best illustrated by the development of glutamic acid with microbial fermentation.

During the early period of the fermentation industry's development, the primary objective was to establish a production technology based on modern sciences. And to attain it, manufacturers and laboratories competed fiercely with each other. From this development race, it was discovered that the production of glutamic acid with microbial fermentation is facilitated by the addition of cofactor substances. The principle of such metabolic

[2] "The Search for Superdrugs," *Business Week*, May 13, 1991, pp. 92–96.

control was later established as a general technological procedure to produce lysine or other amino acids by fermentation.

Sodium glutamate was discovered as the savory component of *kombu*, or seaweed, by Dr. K. Ikeda in 1908 and was subsequently commercialized as a seasoning. Efforts continued to develop production processes and applications for the chemical, and those combined efforts raised the amino acid industry to its present standing.

In the 1950s, worldwide demand for sodium glutamate grew. To overcome the accompanying shortage of new materials and the accumulation of unsold by-products, a need arose to develop new processes enabling the manufacture of chemicals at a low cost with a minimum amount of byproduct. Vigorous research resulted in the development of chemical synthetic and fermentation processes and a combination of the two.

The Ajinomoto Group pioneered the invention of a manufacturing method applying chemical synthesis and a combination of the above two processes, while the Kyowa Hakko Group took the initiative in establishing a manufacturing technology based on fermentation processes. Through a fierce development race run by private businesses around 1955, solid foundations

TABLE 5 Data for Commercially Produced Amino Acids

Amino Acid	Present Source	Potential for Application of Biotechnology
Arginine	Gelatin hydrolysis	Fermentation
Aspartic acid	Bioconversion of fumaric acid	Bioconversion
Citrulline	—	Fermentation
Glutamic acid	Fermentation	De novo synthesis
Glutamine	Extraction	Fermentation
Histidine	—	Fermentation
Leucine	—	Fermentation
Lysine	Fermentation (80%) chemical (20%)	De novo synthesis
Ornithine	—	Fermentation
Phenylalanine	Chemical from benzaldehyde	Fermentation
Proline	Hydrolysis of gelatin	Fermentation
Serine	—	Bioconversion
Threonine	—	Fermentation
Valine	—	Fermentation

SOURCE: Massachusetts Institute of Technology, 1980.

were established for extraction, chemical synthesis, and fermentation processes.

Especially noteworthy was the establishment in 1956 of an industrial fermentation process for glutamic acid production by Dr. I. Kinoshita of the Kyowa Hakko Co. It turned out to be an epoch-making invention that not only brought about a major innovation in the sodium glutamate industry and in the fermentation field at large, but also had a big impact on applied microbiology.

This success triggered rapid progress in research related to amino acid manufacturing methods using microbes. Many new processes derived from these studies, ranging from a glutamic acid fermentation that used wild strains to a direct fermentation process that is applying mutant strains, and included a precursor process developed to avoid metabolic obstruction as well as an enzymatic process that is combined with chemical synthesis. As a result, it became possible to produce almost all types of amino acids with microbes, as shown in Table 5.

Further, the developmental fever coupled with the biotechnology boom in recent years is spurring the adoption of fixation enzymes, cell fusion, and recombinant DNA processes. As these are made available industrially, the progression of amino acid manufacturing technology is accelerating further.

THE EMERGING TECHNO-PARADIGM

Categories of Paradigm Shift

Many specialists have been pointing out changes in the basic pattern of technological innovation.[3] With the emergence of high technology, various changes are occurring in the whole framework of corporate strategy. These changes are significant enough to merit the label "paradigm shift." Table 6 summarizes five categories of paradigm shift.[4]

First, a fundamental redefinition of the manufacturing company is taking place. The manufacturing company was traditionally a site for production, and the economist's formulation is a production function: capital plus labor make things. Yet in many Japanese manufacturing companies, R&D investment is much greater than capital investment. R&D investment surpassed capital investment quite recently and the change occurred rapidly. This signals a paradigm shift; if R&D investment begins to surpass capital

[3] C. Freeman, *Technology Policy and Economic Performance* (London and New York: Pinter Publishers, 1987), pp. 60–79.

[4] F. Kodama, *Analyzing Japanese High Technologies: The Techno-Paradigm Shift* (London and New York: Pinter Publishers, 1991).

investment the corporation could be said to be shifting from being a place for production to being a place for thinking.[5]

TABLE 6 Five Categories of Techno-paradigm Shift

1. Manufacturing companies: from PRODUCING to THINKING ORGANIZATION
2. Business dynamics: from SINGLE to MULTITECHNOLOGY BASIS
3. R&D activities: from VISIBLE to INVISIBLE ENEMIES
4. Technology development: from LINEAR to DEMAND ARTICULATION PROCESS
5. Technology diffusion: from TECHNICAL to INSTITUTIONAL INNOVATION

SOURCE: F. Kodama, *Analyzing Japanese High Technologies: The Techno-Paradigm Shift*, (London and New York: Pinter Publishers, 1991).

Second, there are changes in business. In the past, one technology used to correspond to a given company. But now, especially in Japan, technological diversification has progressed so much that it is hard to distinguish a company's principal business from its secondary business. In many cases the principal business of a company is now overtaken by its secondary business. Today's leading Japanese firms have entered the stage where they survive by adapting to the environment, relying on consistent, dependable R&D.

Third, major changes are observed in the field of research investment decision making in industry. Investment decisions are no longer based on rates of return. It is more like the principle of surf riding: the waves of innovations come one after another and you have to invest; if you miss, you are killed.[6] The pattern of competition is also changing; the competitor used to be another company within the same industrial sector, but in many cases nowadays the competitor is a company in a different industrial sector. Thus high tech companies have to monitor not only direct competitors in their own sector but also firms in other industries. In effect, this means that high tech companies must engage in R&D competition with invisible enemies.

[5] F. Kodama, "The Corporate Archetype is Shifting from a Producing to a Thinking Organization," in "Views of Experts: World Balance of R&D Power," *IEEE Spectrum*, 1990, vol. 27, no. 10, p. 82.

[6] F. Kodama, "How Research Investment Decisions are Made in Japanese Industry," in *The Evaluation of Scientific Research*, D. Evered and S. Harnett, eds., (New York: John Wiley & Sons, 1989), pp. 201–214.

Fourth, there are changes in the technology development process. In the high tech era, the key issue of technology strategy has become not how to break through technological bottlenecks, but how to put existing technology to the best possible use. Accordingly, a day of reckoning has come for technology strategy, that traditionally has emphasized the supply side of technology development. A need has now arisen for a technology strategy which works from the demand side. In developing new strategies to meet this need, the most important element is the process of demand articulation.[7] Through this process, the need for a specific technology manifests itself and the R&D effort is targeted toward developing and perfecting it.

Fifth, the barriers to technology diffusion are shifting from technical problems to institutional inertia. According to Christopher Freeman, the widespread generalization of information technology, not only in the leading branches but also in many branches of the economy, is possible only after a period of change and adaptation of many social institutions to the potential of the new technology. Whereas technological change is often very rapid, there is usually a great deal of inertia in social institutions.[8]

Technology Fusion as an Underlying Trend

We can synthesize those categories of techno-paradigm shift described above around the concept of technology fusion. In other words, the shift of innovation patterns toward technology fusion is a trend underlying all the categories of techno-paradigm shift.

The relationship between technology fusion and manufacturing companies' becoming thinking organizations is observable. Technical terms are increasingly being used as catch phrases for corporate identity and for defining a corporate business domain. For example, C&C (computer and communication) is used by NEC, E&E (energy and electronics) by Toshiba, and IM&M (information movement and management) by AT&T in the United States. As those phrases imply, technology fusion is clearly envisioned, and it is reported that such phrasing has helped to shift these companies' efforts into growth areas.

Technological diversification is at least a necessary condition for technology fusion. It leads to technology fusion, because technological diversification in Japan is attained through diversification of R&D. Through the technological diversification effort already made, Japanese companies have built the fundamental basis for technology fusion.

The techo-paradigm shift in R&D activities will facilitate the realization of technology fusion. One corporate strategy for insuring against the

[7] Kodama, *The Techno-Paradigm Shift*, op. cit., pp.75–84.
[8] Freeman, op. cit., pp. 60–79.

possibility that technical problems will be solved by companies outside a given industrial sector (and that they will profit from them rather than the corporation) is to form technical alliances with companies in other sectors. These cross-sector alliances work not only as a competitive hedge against technological surprises that might be brought about by companies in different industrial sectors, but also as a device that facilitates technology fusion.

Technology fusion is intrinsic to the process of demand articulation, because demand articulation is defined as the search and selection process among technical options. When component technologies are not available within existing technical collections, a long-term technology development effort is needed. However, when demand is well articulated, development activity can be made complementary to the other technologies being developed. In other words, technological development activities through demand articulation drive technology fusion, or sometimes force it.

So we see that the changing focus of manufacturing companies, the diversification of R&D, the changing pattern of R&D activities, and the increasing importance of demand articulation are all related to the increasing importance of technology fusion in creating technologies.

NEW PARADIGM FOR POLICYMAKING

This shift in the techno-paradigm is making obsolete the policy arguments of science and technology that have hitherto been common sense in theories of business administration and international relations. As a result of a lack of full appreciation of the paradigm shift in science and technology, there are mismatches in management practices, paradoxes in economic policy[9] and international disputes are becoming more pronounced. High technology may thus change the conventional wisdom in theories of business administration and international relations.

Corporate Strategy: New Technical Alliances

The inadequacy of solutions for trade friction, based on the old paradigm of trade theory, can be best illustrated by the U.S.-Japan trade agreements in two important industrial sectors: the automobile and semiconductor industries. The dispute in the former after the oil crisis added a new term to the lexicon of international trade, the "voluntary export restraint" (VER) by Japanese manufacturers, although there had been earlier versions for color televisions and steel. In fact, this is a very subtle way to avoid an inconsistency between the ideals of "free trade" and its real practices.

[9] Organization for Economic Cooperation and Development, *STI Review* , July 1990, no. 7, p. 5.

In the U.S. market, Japanese cars seem to dominate the mass production segment, while European makers control the luxury niche. But due to U.S. import restrictions imposed on cars, Japanese auto makers now hope to move into the luxury market, competing with the smooth-riding Mercedes Benz models. In order to replicate the well known operating comfort of Mercedes, Japanese auto makers seem to be relying on automated precision electronics technology, rather than mechanics. In other words, mechatronics is making this transition possible. Japanese auto companies are approaching the problem through a different technological trajectory—technology fusion.

In 1986 the U.S.-Japan Semiconductor Trade Agreement was signed. It was the first U.S. trade agreement dedicated to improving market access abroad rather than restricting market access at home. Unlike previous bilateral trade agreements, it attempted to regulate trade not only in the United States and Japan but in other global markets. [10]

In the new techno-paradigm, however, basic high tech problems are occasionally solved by ideas or technologies born in totally unrelated fields. Leaders in technological advances come to dominate their predecessors in an established industry; revolutionary innovation coincides with a change of leadership. The change of leadership will more and more occur across national boundaries, thus making it impossible to define international competition in technological development using conventional patterns.

As the challenge for high tech leadership comes from seemingly unrelated industries, without regard to the country of origin, international agreements among companies in the same industrial sector to avoid competitive pressure could easily be rendered meaningless. Conversely, companies could form technological alliances across national and industrial boundaries, competing for development. The technological alliances between companies, that belong to different industrial sectors, and are located in different countries, might facilitate the realization of technology fusion.

Government Policy: New Research Consortia

The new technological paradigm also presents challenges for government policies to promote innovation. The evolution of Japan's government-sponsored R&D consortia in recent years illustrates how technology fusion is increasingly taken into account in Japanese policymaking. The Japanese experience may hold some lessons for U.S. policymakers attempting to structure effective support for commercially oriented collaborative research.

[10] D. Yoffie, "Technology Challenges to Trade Policy," presented to National Academy of Engineering Symposium on Linking Trade and Technology Policies, National Academy of Sciences, Washington, D.C., June 10–11, 1991.

In the United States, precompetitive research is usually carried out at a university under the sponsorship of several private corporations. This represents a chronological, linear concept of technological innovation, in which research begins at the scientific stage and progresses through the application and development stages. In Japan, however, precompetitive research achieved through research associations is better represented by plotting industrial linkages on a graph of coordinates, in which the goal is to create engineering infrastructure as the basis for competition.[11] This is especially true when it comes to the creation of fusion-type innovations.

The VLSI (very large scale integration) research association is a model of how government policy can speed technology fusion, and represented a turning point for Japanese R&D consortia. The project included all five of Japan's IC (integrated circuit) chip manufacturers at the time. In this research association, rather than focusing on the method of production itself, research efforts emphasized developing a prototype for IC manufacturing equipment.

In other words, potential users of manufacturing equipment joined together to articulate their needs. This demand articulation clarified the technical path for semiconductor manufacturing equipment, and facilitated an information flow between the potential suppliers and the IC makers. On the basis of this information, the suppliers—largely firms new to the business of semiconductor manufacturing equipment—were able to make the long-term investments necessary to enter this new field.

The Engineering Research Association (ERA) for VLSI existed from 1976 to 1979 and spent a total of ¥73.7 billion, of which ¥29.1 billion was paid by the government on a project funding basis. Members of the association were Fujitsu, Hitachi, Mitsubishi (Electric), NEC, and Toshiba. These five companies established a joint research laboratory within the association.

A large percentage of the research and development carried out in the joint research laboratory was subcontracted to the supplier companies, which were not members of the association. Suppliers that were heavily involved included Nikon, which developed the optical wafer stepper; JOEL, which developed electron beam lithography; printing companies, which developed lithography; and silicon crystal suppliers.

In Figure 1, major actors involved in the Japanese development of VLSI and the technical linkages among them are depicted.[12] The specific activities of the association included the development of the optical stepper. The lithography research laboratory sought to reduce the electronic circuit onto the silicon base optically, not electronically. Therefore, this laboratory

[11] Kodama, *The Techno-Paradigm Shift*, op. cit., pp.93–107.

contracted research to camera manufacturers who owned the lens technology, and thus companies such as Nikon and Canon succeeded in developing the optical stepper.

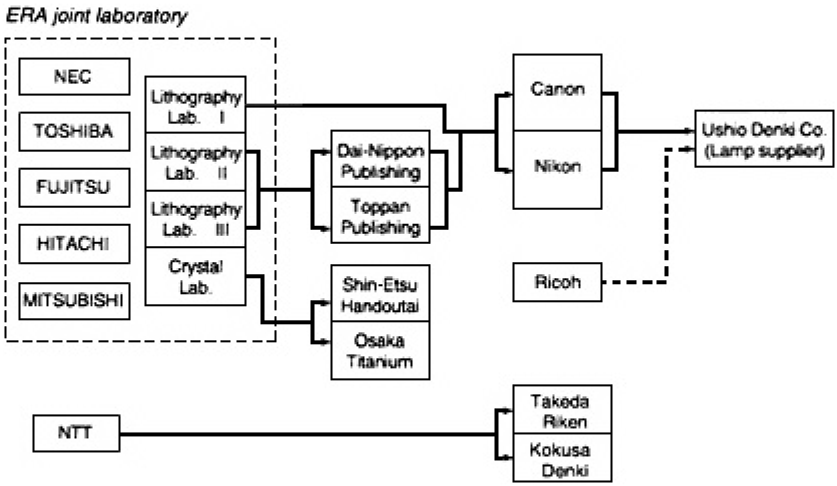

Figure 1 Upstream linkages of Japanese VLSI development. Source: Fumio Kodama, Analyzing Japanese High Technologies: The Techno-Paradigm Shift, (London: Pinter, 1991), p. 89.

By gathering the major chip manufacturers together, the articulation of demand for semiconductor manufacturing equipment was encouraged. In this way, technology fusion between optical and electronics technologies was realized through the efforts of demand articulation by the chip manufacturers.

The shift to technology fusion is well reflected in recent changes in the way in which research consortia are organized. The analysis of membership in research associations reveals that the average number of industrial sectors per project is increasing, while the number of participating companies per industrial sector is stable or decreasing. In other words, collective research increasingly combines firms in different industrial sectors rather than different companies within the same industrial sector.[13]

[12] Ibid., pp. 87–93.

[13] In our analysis of membership in research associations, those collective research projects without any participation of companies whose stock is registered in the open stock market, are excluded in our data base. Thus, 88 research associations were selected for our study. See I. Shirai and F. Kodama, "Quantitative Analysis on Structure of Collective R&D Programs by Private Corporations in Japan, NISTEP Report No. 5" (Tokyo: National Institute of Science and Technology Policy, August 1989).

TABLE 7 Classification of Member Enterprises by Industrial Sector per Engineering Research Association

Time Period	Number of Projects	Number of Industrial Sectors per Project	Number of Registered Companies per Industrial Sector
1961–1964	3	3.0	3.2
1965–1969	0	—	—
1070–1974	13	2.2	3.0
1975–1979	14	3.4	3.4
1980–1984	35	3.9	3.3
1985–	23	4.3	3.2
Total	88	3.6	3.2

SOURCE: I. Shirai and F. Kodama, "Quantitative Analysis on the Structure of Collective R&D Programs by Private Corporations in Japan, NISTEP Report No. 5" (Tokyo: National Institute of Science and Technology Policy, August 1989).

For the entire 30-year history of the research association system, the average number of industrial sectors per project is 3.6, and the number of participating companies per project is 3.2. The research associations are divided into six cohorts based on the date of establishment. The time periods for the six cohorts are shown in Table 7. The average number of industrial sectors represented in the 13 research associations established between 1970 and 1974 is 2.2 sectors per project. This number has increased steadily since. It has risen to 4.3 sectors per project in the 23 research associations established after 1985.

On the other hand, the average number of participating companies per industrial sector has held steady at about three. This illustrates the shift in how research consortia are organized. In the past, collective research was organized mainly among companies belonging to the same industrial sectors. However, it is now being organized among companies in different sectors.

Over the past several years, the Japanese government has indicated that it intends to go further along this path. ISTEC, the International Superconductivity Technology Center established in 1988, was one of the first Japanese consortia to invite foreign participation. A wide range of industries are represented as members, including service industries such as banking. The importance of foreign participation to future collaborative research in Japan is indicated by steps the government is taking to make it easier for foreign firms to join Japan's national projects, and by the fact that the

Intelligent Manufacturing System, micromachine, and other new programs were conceived as international projects.

In terms of technology fusion, we make the following interpretation: the networking of different kinds of "technological competence," [14] owned by different companies in different industrial sectors and different countries, is being created by government-organized research consortia. In this way, policy can play the key networking role of matching competencies and needs. The benefits of the consortia go beyond the R&D subsidy value, because networks are formed more quickly than if the initiative had been left entirely to the firms themselves. Technical and market information exchanged through these relationships will lead to faster corporate investment in innovation.

Japan's experience has relevance for U.S. policymakers. The U.S. government has increased support for collaborative research in recent years. Examples include SEMATECH, the Department of Commerce's Advanced Technology Program, and the Department of Energy's battery consortium among the Big Three automakers. If the Japanese experience is valid and if technology fusion is facilitated by wide industry membership in collaborative research, the United States might benefit from focusing on bringing a variety of competencies into consortia.

The American position on foreign participation in government-sponsored collaborative research is unclear at this point. But increasingly, technical competencies are found in firms throughout the world. Therefore, by excluding foreign nationals from government-sponsored research consortia, a country risks limiting technology fusion. It should not be assumed that a country can cover the entire spectrum of needed technological competence. The inclusion of foreign companies that have unique technical competence, therefore, might enhance the probability that global technological networking will result in heightened technology fusion in fields in which domestic organizations do not have high competence.

[14] S. G. Winter, "Knowledge and Competence as Strategic Assets," in D. Teece, ed., *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, (Berkeley: Center for Research in Management, University of California, 1987), pp. 159–184.

Japan's Industrial Competitiveness and the Technological Capabilities of the Leading Japanese Firms

JOHN CANTWELL

NATIONAL SYSTEMS OF INNOVATION AND CHANGES IN TECHNOLOGICAL LEADERSHIP

In an influential recent book Mokyr[1] set out the case for what he termed "Cardwell's Law," based on an interpretation of Cardwell.[2] This Law proposes that highly technologically creative societies only remain so for relatively short historical periods. At some stage the momentum that gathers behind technological advance becomes exhausted. In Mokyr's judgment, the Law has the status of an observed empirical regularity. Technological leadership changes from time to time, moving from one society to another. In recent history, technological leadership has passed from Britain to the United States, and in very recent times it has switched from the United States to Japan.

A complementary perspective on these occasional changes in technological leadership has been provided by Schumpeterian economists such as Freeman and Perez.[3] Schumpeter had held that long waves of economic development are initiated by pervasive new technologies that have an impact

[1] J. Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (Oxford: Oxford University Press, 1990).

[2] D.S.L. Cardwell, *Turning Points in Western Technology* (New York: Neale Watson Science History Publication, 1972).

on every major industry.[4] The diffusion of steam power and electric power provide examples. According to Freeman and his associates, these periods of economic transformation depend upon the consolidation of a new technological system or techno-economic paradigm. The new system or paradigm encompasses a broad range of related technological development that goes beyond the best known major innovations that characterize the leading sectors.

In this context, a technological paradigm is defined as a widespread cluster of innovations that represent a response to a related set of technological problems, based on a common set of scientific principles and on similar organizational methods.[5] The organizational methods associated with different paradigms require the support of different kinds of social institutions. Therefore, it is not surprising that with the emergence of a new paradigm technological leadership tends to move away from a society whose institutions were particularly geared towards problem-solving activity within the confines of the previously prevailing paradigm. Leadership is likely to pass to a society whose institutions are more adaptable to and better represent the organizational structures needed to promote the most pervasive new technologies.

In a new technology paradigm every country must adjust its national system of innovation. The national system of innovation is the network of institutions in the public and private sectors that support the initiation, modification and diffusion of new technologies.[6] In the paradigm based on mass production that dates from the interwar period, U.S. institutions led the way. The typical national system of innovation relied on the establishment of specialized corporate R&D departments, increasing state involvement in civil science and technology, and the rapid expansion of secondary and higher education and industrial training. The new technology paradigm now taking shape is instead grounded on the economies of scope gained through an interaction between flexible but linked production facilities, in which individual plant flexibility and network linkages both depend upon the new information and communication technologies. The pioneers in this case are Japanese institutions. The appropriate national system of innovation today emphasizes the closer integration of R&D, production and marketing within firms, technological cooperation between firms, generalized education and training to provide a work force with multiple rather than specialized skills, and state support for generic technologies.

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[3] C. Freeman and C. Perez, "Structural Crises of Adjustment: Business Cycles and Investment Behaviour," in G. Dosi, C. Freeman, R.R. Nelson, G. Silverberg, and L.L.G. Soete, eds., *Technical Change and Economic Theory* (London: Frances Pinter, 1988).

[4] J.A. Schumpeter, *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process*, 2 vols. (New York: McGraw Hill, 1939).

[5] G. Dosi, *Technical Change and Industrial Transformation* (London: Macmillan, 1984).

[6] C. Freeman, *Technology Policy and Economic Performance: Lessons from Japan* (London: Frances Pinter, 1987).

Each technological paradigm is characterized by a set of technological opportunities that can be very different from the opportunities that typified the paradigm it replaces. In the U.S.-led paradigm the greatest opportunities appeared in energy and oil-related technologies and in scale intensive systems. In the paradigm in which Japan is to the fore the best opportunities are in microelectronic technologies and in computerized systems. To take full advantage of these technological opportunities national systems of innovation must be adapted accordingly. However, this is a difficult process, especially in the countries that were the most heavily committed to the previously dominant production methods. Although all countries strive to adjust their national systems to the opportunities opened up by the new paradigm they have varying degrees of success, and significant differences in cross-country institutional structures remain.

For this reason differences in industrial competitiveness between countries tend to persist over time within a paradigm, and substantial alterations in the competitive ranking of countries only tend to occur during the windows of opportunity provided by paradigm changes. Cross-country variations in the details of national systems of innovation are associated with fairly systematic differences in rates of technological change across countries once a new paradigm has become established. After a paradigm has settled down, these differences in national systems of innovation are sustained not so much by some natural or inherent cultural characteristics of different societies (despite the fact that this is a common interpretation in popular discussions), but rather result principally from the cumulative and path-dependent nature of technological change itself. While in some respects the international diffusion of new technology brings production systems closer together, in other respects technological development reinforces differences between countries and firms.

In their seminal work in this field, Nelson and Winter laid the theoretical foundations for our understanding that technological change is typically cumulative, incremental and differentiated.[7] Their theoretical conclusions were entirely consistent with the insights gained from historical studies of technological evolution by Rosenberg.[8] Because technological change is differentiated between firms and between countries, the differences between them persist over time; and because technological change is cumulative and incremental, existing leaders tend to preserve their position within the confines of an unchanged paradigm. As will be explained at greater length in

Section 2, leaders are defined here with reference to the current rate of technological change and not the absolute level of technology accumulated from the past.

Economists often find it hard to understand this idea that persistent differences in the production methods of firms and countries may result from an interactive process of technological change. This is for a variety of reasons, but one is that economists tend to think of technology simply as a matter of applied science or engineering rather than as a matter of organization. Until recently, when thinking of economic organization economists have focused almost exclusively on the market as the means of organizing production and other economic activities, and have disregarded the role of firms and other institutions. Indeed, where they have considered firms they have usually depicted them as an alternative to markets,[9] taking the market as a reference point instead of treating the technological and organizational evolution of firms in its own right. If technology can be reduced to scientific and engineering knowledge or information then on the condition that markets work well, technological differences will be short-lived, owing to the scope for trade in this information.

Technology is more accurately described as consisting of two strictly complementary components.[10] The first is the element that has been emphasized in the conventional economics literature, namely generic knowledge. Such knowledge has the characteristics of a latent public good, it is potentially tradable, and its public availability and diffusion bring the production systems of firms and countries closer together. The second element, which is emphasized in the new Schumpeterian and allied literature, is the tacit component of technology embodied in the collective skills and organizational routines of firms. This element is specific to the localized conditions under which technology is created and used, and while it can be imitated by others it cannot be directly copied in exactly the same form. It is therefore in itself nontradable, irrespective of how well markets work, although under agreements for technological cooperation, contracts can be devised for technical assistance that reduce the costs of imitation. So despite the diffusion of generic knowledge, technological differences between countries and firms remain. The tacit component of technology represents

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[7] R.R. Nelson and S.G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge, Mass.: Harvard University Press, 1982).

[8] N. Rosenberg, *Perspectives on Technology*, (Cambridge: Cambridge University Press, 1976) and *Inside the Black Box: Technology and Economics* (Cambridge: Cambridge University Press, 1982).

[9] R.H. Coase, "The Nature of the Firm," *Economica*, vol. 4, no. 4., 1937 and O.E. Williamson, *Markets and Hierarchies: Analysis and Antitrust Implications* (New York: Free Press, 1975).

the essential source of the continuing discrepancies in technological competitiveness or competence observed across countries and firms. [11]

One important aspect of the differences in national systems of innovation is that countries and firms tend to evolve significantly different patterns of technological specialization. The distinctive composition of the distribution of technological activities in individual countries and firms again persists, especially over shorter periods of time. This is particularly true of countries or of national groups of firms. [12] These differences in national patterns of specialization provide a measure of how well a country and its leading firms have become accommodated to the prevailing technology paradigm. The paradigm is characterized by certain pervasive technologies in which opportunities (for development and application) are at their greatest. Technological activities that are the most closely related to these critical fields also offer attractive opportunities. A national system of innovation that is finely tuned to the new paradigm establishes a pattern of specialization that is relatively concentrated in these areas of strong potential growth.

The leading role of Japan in the current technology paradigm can be examined in these terms. For some years now, Japan's specialization in technological activity has emphasised the fields that have become dominant in the new paradigm. The specialization that derives from Japan's national system of innovation is thus associated with a systematically higher overall rate of technological change. A specialization in what have become the pervasive new technologies directly raises the overall rate of technological progress since it entails a concentration of activity in branches in which growth is fastest. The overall rate of innovation also increases indirectly, as advances in these critical areas lead to greater spillover benefits in other fields.

The favorable relationship between the Japanese pattern of technological specialization and the distribution of technological opportunities across fields of activity can be illustrated from an analysis of U.S. patent data. The composition of technological specialization can be measured through the construction of an index of what has been termed revealed technological advantage, or RTA.[13] Revealed technological advantage is defined as the

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[10] R.R. Nelson, "The Public and Private Elements of Technology," mimeo, (New York: Columbia University, 1990) and J.A. Cantwell, "The Theory of Technological Competence and Its Application to International Production," in D.G. McFetridge, ed., *Foreign Investment, Technology and Growth* (Toronto: University of Toronto Press, 1991).

[11] D.J. Teece, G. Pisano, and A. Shuen, "Firm Capabilities, Resources and the Concept of Strategy," *University of California at Berkeley Consortium on Competitiveness and Cooperation Working Papers*, No. 90-8, December 1990 and Cantwell, op. cit., footnote 10.

[12] J.A. Cantwell, "Historical Trends in International Patterns of Technological Innovation," in J. Foreman-Peck, ed., *New Perspectives on the Late Victorian Economy: Essays in Quantitative Economic History 1860–1914* (Cambridge: Cambridge University Press, 1991) and P. Patel and K. Pavitt, "Large Firms in the Production of the World's Technology: An Important Case of Non-Globalisation," *Journal of International Business Studies*, vol. 22, no. 1, 1991.

national share of patenting in a particular field (in this case, the share of patents granted attributable to inventors resident in Japan) relative to the national share of total patenting in all fields. The RTA index thus approximately varies around unity, with the highest values assigned to the fields of greatest local specialization. The fields of technological activity are derived from the U.S. patent class system.

Figure 1 plots the relationship between the distribution of the Japanese RTA index in the 1960s and the growth of total U.S. patenting between the 1960s and the 1980s. The index was calculated across 33 sectors of technological activity, which for the purposes of the diagram have each been assigned to one of ten groups. The positive association between Japan's national pattern of technological specialization and the subsequent extent of technological opportunities across sectors is evident from the estimated regression line. In this regression the coefficient on RTA was significantly different from zero at the I percent level. The fields of greatest opportunity in which Japan was most heavily specialized were (in electrical equipment) computers, calculators and other office equipment, and image and sound equipment or radios and televisions, and (in instruments) photography and photocopying. It can also be shown that Japan's concentration of activity in the areas of the fastest technological change is much greater than for the United States or any other country, although this is partly attributable to the somewhat narrower focus of technological specialization in Japan than in the United States.[14]

Owing to the cumulative and incremental characteristics of technological change, the degree of mobility in Japan's national pattern of technological specialization over the last 20 or 30 years has not been very great. [15] Therefore, so long as the distribution of technological opportunities across sectors remains similar, Japan is likely to sustain her high rate of technological change. The distribution of opportunities is largely a function of the prevailing technological paradigm. Indeed Japan's position has improved in this respect, since the period between the 1960s and 1980s was one of transition from a paradigm that favored the U.S. national system of innovation to one that favors the Japanese.

The high rate of technological change achieved in Japan and by Japanese based firms has had major economic consequences and will continue. It has supported a higher rate of economic growth such that Japan has steadily increased her share of world exports and (since local wages lag

[13] L.L.G. Soete, "The Impact of Technological Innovation on International Trade Patterns: The Evidence Reconsidered," *Research Policy*, vol. 16, no. 1, 1987 and Cantwell, op. cit., footnote 12.

[14] D. Archibugi and M. Pianta, "Patterns of Technological Specialisation and Growth of Innovative Activities in Advanced Countries," in K. Hughes, ed., *European Competitiveness* (Cambridge: Cambridge University Press, 1992, forthcoming).

[15] J.A. Cantwell, *Technological Innovation and Multinational Corporations* (Oxford: Basil Blackwell, 1989).

behind productivity improvements) established a regular trade surplus. Meanwhile the leading Japanese companies have on average grown faster than their major international rivals, and have consistently increased their share of international markets through exports and international production. The position in international trade and production of national groups of firms depends upon their specific areas of technological strength.[16]

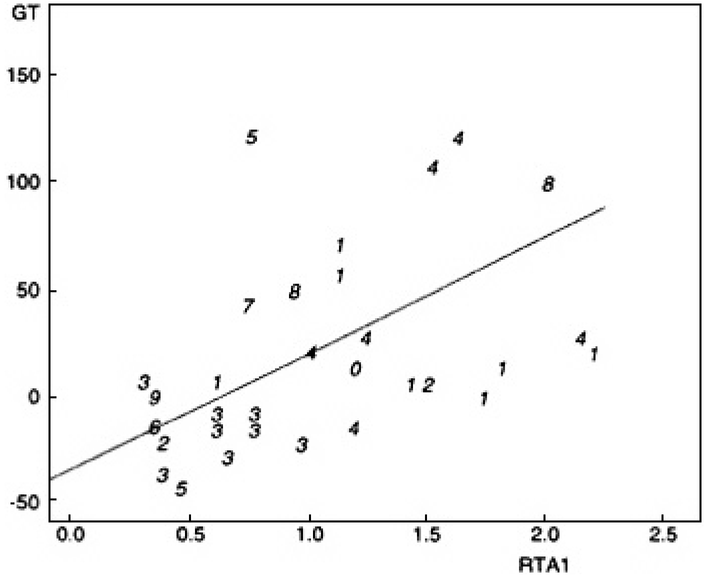

Figure 1 The relationship between the growth of total U.S. patenting from 1963–1968 to 1981–1986 and Japanese revealed technological advantage (RTA) in 1963– 1968. Note: One observation hidden. Sector codes: 0, Food products; 1, Chemicals and allied; 2, Metals; 3, Mechanical engineering; 4, Electrical equipment; 5, Transport equipment; 6, Textiles and wood products; 7, Nonmetallic mineral products; 8, Professional and scientific instruments; 9, Other manufacturing and nonindustrial.

If the Schumpeterian perspective is a reasonable one the competitive success or failure of countries or firms (as measured by their growth rates and hence the change in their market shares) is essentially a function of the rate of technological change they are able to sustain. To formalize this

[16] B. Kogut, "Country Patterns in International Competition: Appropriability and Oligopolistic Agreement," in N. Hood and J.E. Vahlne, eds., *Strategies in Global Competition* (London: Croom Helm, 1987) and G. Dosi, K. Pavitt, and L.L.G. Soete, *The Economics of Technical Change and International Trade* (Hemel Hempstead: Harvester Wheatsheaf, 1990).

view of the Japanese experience a simple model of the relationship between innovation and growth is set out in the next section. This is briefly related to the evidence on the association between technology and growth when comparing Japan with other countries. In the section following, this approach to technology and growth is extended to a consideration of evidence at the company level. It is also shown that the locally specific pattern of technological specialization of a national group of firms contributes to the rate of technological change that they achieve. When examining firms, comparisons of technological development and the evolution of market shares must be made at the industry level. To this end, data on the world's largest industrial firms are considered, given that these companies constitute one anothers' major competitors in the main international industries. In conclusion, some conclusions and suggestions pertaining to the likely future competitive performance of Japan and the United States (and of Japanese and American companies) are discussed.

A MODEL OF THE ASSOCIATION BETWEEN TECHNOLOGICAL CHANGE, GROWTH AND COMPETITIVENESS

The basic idea explored in the model formulated here is that the essential source of differences in the level of productivity across countries and firms (and hence differences in living standards in the national case) is the level of technological capability that they have accumulated from the past. Technological improvements are in part embodied in new capital equipment or other tangible assets, so the accumulation of technological ability is linked to the process of capital accumulation. However, technological progress is also partly disembodied in the form of collective skills and organizational expertise, and the relative significance of this tacit element of technological capability may increase over time.

So in this model the level of accumulated technological capability determines the level of productivity and output. It follows that the rate of technological accumulation determines the rate of growth of productivity, the growth of output, and the rate of capital accumulation. This is a Schumpeterian model in the sense that the rate of technological innovation determines growth, and hence the competitive strength of countries and firms as measured by gains and losses in their market shares. However, it is a relatively simple model, and it is not intended as a formalization of Schumpeter's own views. Schumpeter himself emphasized the process by which competitors tend to catch up with innovative leaders, and in this respect at least he remained faithful to the conventional economist's view of the effect of technology diffusion. As already explained, the more recent Schumpeterian tradition allows that a continued divergence in rates of technological change may be expected to persist in the context of an unchanged paradigm.

In addition, the model here makes no reference to the role of individual entrepreneurs, which was important to Schumpeter.

The model is sufficiently general that it can be applied either at the level of national economies or at the level of firms. It begins from a set of standard identities and definitions as follows:

$$Q = AN \quad (1)$$
$$Q = W + \pi \quad (2)$$
$$K = k^* Q \quad (3)$$
$$W = xQ \quad (4)$$
$$\pi = (1 - x)Q \quad (5)$$
$$w = W/N \quad (6)$$
$$r = \pi/K = (1 - x)/k^* \quad (7)$$

The value of output is denoted by Q; A is the value of labor productivity; N is employment; W is the total wage bill; is the value of total profits; K is the value of accumulated capital stock; k^* is the constant capital-output ratio; x is the share of wages in output; w is the wage rate; and r represents the rate of profit. The (approximate) constancy of the capital-output ratio is a stylized fact of normal economic development, which is used here to avoid unnecessarily complicating the analysis. On the further simplifying assumption that all profits are reinvested as set out in equation (8) (where I denotes the value of investment), the rate of economic growth can be derived:

So

$$\pi = I = K' \quad (8)$$
$$\dot{Q} = \dot{K} = r = (1 - x)/k^*$$

Prime signs are used to depict derivatives (so $K' = dK/dt$ and $K'' = d2K/dt2$) and dots over letters indicate proportional rates of growth (so $Q = (1/Q)(dQ/dt) = Q'/Q$).

Now two further equations, which represent the essence of the argument above, can be used to close the model and to define its dynamic properties:

$$A = m^* + u^* T \quad (9)$$
$$x = x^*/(1 + \dot{A}) \quad (10)$$

In equation (9), T is the accumulated stock of technology and u^* is the constant coefficient of responsiveness of the current level of productivity to the technology stock. In equation (10), x^* is the share of wages in output that would prevail if technological accumulation and thus productivity growth ceased. In this event the growth rate would be fixed at $(1-x^*)/k^*$. The intuition that underpins equation (10) is that if innovation ceased the wage rate would be directly proportional to the level of productivity, but with technological change wages only follow productivity with a lag. Consequently, the higher the rate at which productivity growth is sustained, the lower is the ratio of the wage rate to productivity [where $x = w/A$, from equations (1), (4), and (6)].

Now with the rate of technological accumulation given by $\dot{T}$, this determines the rate of productivity growth, since from equation (9):

$$\dot{A} = \dot{T}$$

By substituting into equation (10);

$$x = x^* / (1 + \dot{T})$$

The growth rate is now given by

$$\dot{Q} = \dot{K} = [1 - x^* / (1 + \dot{T})] / k^*$$

Hence, in this model output growth and capital accumulation as well as productivity growth come to depend upon the rate of technological accumulation. Countries or firms that achieve higher rates of technological advance also experience faster growth rates and so improve their market shares.

The wage rate and its path over time can also be derived:

$$w = xA = x^* (m^* + u^* T) / (1 + \dot{T})$$
$$\dot{x} = (\dot{T}^2 - T'' / T) / (1 + \dot{T})$$
$$\dot{w} = \dot{x} + \dot{A} = (\dot{T}^2 - T'' / T) / (1 + \dot{T}) + \dot{T}$$

If the rate of technological accumulation were constant (say, $\dot{T}=c$) then the other growth rates would also be fixed:

$$\dot{Q} = \dot{K} = [1 - x^* / (1 + c)] / k^*$$
$$\dot{x} = 0$$
$$\dot{w} = \dot{T} = \dot{A}$$

Returning to an issue mentioned in passing earlier, the leading countries or firms in a technological paradigm are those that enjoy a consistently higher rate of technological accumulation, and thereby in this model sustain a faster rate of growth. However, especially in the early stages of a new paradigm, and if there has been a change in leadership from the previous paradigm, these new leaders are unlikely to be the countries or firms that have the largest accumulated technology stock. This is instead likely to be the province of the former leaders, who achieved a higher rate of accumulation in the past. High levels of technology stock, and productivity (and at a national level, living standards) reflect past rather than current performance.

The stock of the codifiable element of technology can be measured by the stock of patents or capitalized R&D expenditure, with an allowance for depreciation (in terms of their current effect upon productivity). The rate of technological accumulation may then be measured by the current increase in technology (the annual flow of patents or R&D expenditure) relative to the stock. The model just outlined suggests that this may be the best measure of technological competitiveness. Another commonly used measure of such competitiveness is the ratio of the increase in technology relative to the level of output (*T'/Q* in the notation above), such as R&D spending relative to the gross domestic product (GDP). Because of their role in empirical studies, it is worth exploring the implications of the system for the evolution of the (*T'/Q*) and (*T/Q*) ratios.

With plausible values of the relevant parameters—namely x^* close to unity and k^* greater than unity—the (*T/Q*) ratio gradually rises over time. That is, there is a tendency for production to become steadily more "technology-intensive." The path of the (*T/Q*) ratio is defined by

$$\dot{T} - \dot{Q} = \dot{T} - [1 - x^*/(1 - \dot{T})]/k^*$$

$$\dot{T} - \dot{Q} = [(k^* - 1)\dot{T} + k^*\dot{T}^2 - (1 - x^*)]/k^*(1 + \dot{T})$$

So

If x^* ` 1 and $k^* > 1$ then the expression on the right hand side is positive and the (*T/Q*) ratio rises. An assumption that x^* is close to unity summarizes the Schumpeterian view. Since $\dot{Q} = [1 - x^*/(1 + \dot{T})]/k^*$, it follows that if $\dot{T} = 0$ with $x^* = 1$ then $\dot{Q} = 0$. In other words, in this case if there is no innovation, growth ceases and the economy collapses into a stationary state. In this state profits fall to zero; profits depend upon regular technological improvements. Indeed, a country or firm that completely fails to innovate may even find that under competitive pressures its output declines ($x^* > 1$). An assumption that $k^* > 1$ is also reasonable. This simply states that the value of accumulated capital stock is greater than the value of current output.

Under these conditions the (*T/Q*) ratio is a measure of past technological achievements. A stronger rate of technological accumulation in the past leads to a higher (*T/Q*) ratio. This helps to explain why the truly backward (with a low level of technological capability) may find it so difficult to catch up with the truly advanced (with a high level). If technology intensity rises with growth so does the contribution to output of the tacit component of technology, which cannot be directly traded or transferred between firms.

The (*T'/Q*) ratio represents the combined product of current and past technological competitiveness as

$$T'/Q = \dot{T}(T/Q)$$

So the (*T'/Q*) ratio can be used as a measure of technological competi tiveness as it reflects the present rate of technological accumulation $(\dot{T})$,but it is a measure that is also weighted by the record of the past. This view is entirely consistent with evidence on the relationship between Japanese technological capability and economic performance. Japan (like Germany) experienced a faster growth of R&D and patenting than did other countries from the 1950s onwards, and with this came a faster growth of productivity and output. However, in the 1960s Japan's ratio of nondefense R&D to GDP was below that of the United States, but she overtook the United States on this measure in the early 1970s.[17] So after a while Japan's higher rate of technological accumulation $(\dot{T})$ was reflected in a higher (*T'/Q*) ratio. In the 1970s, though, Japan's absolute level of technological capability (*T*) and productivity remained below that of the United States. Even in terms of the absolute levels of technological capability and productivity, Japan appears to have caught up with the United States by around the late 1980s. So a high rate of technological accumulation $(\dot{T})$ ensures higher growth, and if this is sustained it is reflected in a higher (*T'/Q*) ratio for the country or firm, and eventually it also leads to a high absolute level of technological capability (*T*).

Implicitly, the model supposes that countries that achieve higher rates of technological accumulation increase their share of world trade and production (as has Japan), and firms that do so increase their world market shares (as have the leading Japanese companies). This is consistent with the evidence on trade and technological competitiveness [18] and on company performance. A model of this kind can also be used to contribute to an explanation of Japan's trade surplus position and a regular trade deficit in a country (such as the United States) in which the current rate of technological accumulation has been lower.[19]

Of course, differences in industrial and technological competitiveness at a time when production has become more internationally mobile are far from being the only explanation of trade imbalances between countries. It is important to also take account of policy differences between governments. Countries with highly expansionary fiscal policies and (it is argued by some) an absence of strategic trade policy may find their trade position weakened relative to countries whose government policy stance is at the opposite extreme. However, in conventional models the trade imbalances that arise in this way are corrected by exchange rate (relative price) movements; and indeed the inflationary consequences of a currency depreciation

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[17] Freeman, op. cit.

[18] J. Fagerberg, "International Competitiveness," *Economic Journal* , vol. 98, no. 3, 1988 and Dosi, et al., op. cit., footnote 16.

[19] Cantwell, op. cit., footnote 15.

in a deficit country may lead to the abandonment of a highly expansionary fiscal policy. Paul Krugman has recently shown that the overvaluation of the U.S. dollar and the absence of exchange rate adjustment contributed to the especially large U.S. trade deficit of the mid-1980s. This sustained overvaluation can be attributed to financial considerations related to the U.S. government's budget deficit and high interest rates. Yet even after depreciation, a sizable imbalance in trade between the United States and Japan still remains.

Macroeconomists have explained this residual trade imbalance by international differences in the propensity to save out of income. A country in which the propensity to save is low tends to attract an inflow of investment funds from savings in other countries, which in equilibrium matches the trade deficit that is associated with a high propensity to consume. The deficit country exchanges financial assets for goods, and so long as this continues there is no downward pressure on its currency. However, differences in the propensity to save must still be explained. One popular explanation is more sociological than economic; American culture encourages borrowing, while the Japanese are typically thrifty.

The model of technological competitiveness suggested here provides an alternative or additional perspective on the international differences in savings rates that are associated with persistent trade imbalances. It has been supposed that with technological accumulation, productivity growth tends to run ahead of a rise in wages. Thus a faster rate of accumulation of technology generates a higher share of profits and lower share of wages in income. If it is then further assumed, as seems reasonable, that the propensity to save out of profit income is higher than the propensity to save out of wage income, then it follows that a higher rate of technological change is linked to a higher propensity to save at a national level. In other words, if productivity growth runs ahead of a rise in wages, it is likely that the growth of output will run ahead of the increase in consumption in each location. A country such as Japan, with a rapid rate of technological accumulation by world standards, can be expected to have a high propensity to save relative to other countries, and hence a trade surplus.

TECHNOLOGICAL CHANGE AND GROWTH IN THE LEADING JAPANESE INDUSTRIAL FIRMS

The linkage just proposed between technological accumulation and economic growth is also worth investigating at the company level. With this in mind, the performance of the leading Japanese industrial firms since the late 1960s can be compared with that of their major world rivals, drawing on a data base held at the University of Reading.

The analysis is based on the world's largest 792 industrial firms according to the value of their global sales in 1982.[20] The value of these sales in 1972 and 1982 serves as a proxy for their output in the early 1970s and early 1980s respectively. The flow of new technology is measured by the number of patents granted in the United States to the same firms, consolidating patents granted to affiliated companies in the same fashion as in the calculation of global sales. Of the original 792 firms, 267 were excluded due to a lack of information on the value of their world sales in 1972, and a further 10 were excluded as they had no record of patenting in the United Staes. This left a final sample of 515 firms, of which 275 were U.S. owned, 78 were Japanese, 137 were European, and 25 originated from other countries (mainly from Canada). Each firm was also allocated to a primary industry of activity.

It is not possible to form an accurate estimate of the rates of technological accumulation enjoyed by these firms without knowing their levels of patenting prior to 1969 (from which to calculate a technology stock). However, it can be asserted with a reasonable degree of confidence that by the late 1960s the rate of technological change in the leading Japanese firms already exceeded that in their major U.S. and European competitors. While the patenting of all Japanese residents in the United States was very low until the early 1960s, by 1970 the leading Japanese firms had attained substantial levels of U.S. patenting. The Japanese firms in the sample were granted an average of nearly 100 patents each in the United States in 1969–1972.

Associated with their higher rates of technological change, this group of Japanese firms achieved a higher rate of output growth. Their combined sales grew more rapidly between 1972 and 1982 than the equivalent sales of their U.S. and European competitors in all industries except two. The two exceptions were pharmaceuticals (in which industry technological change may still have been higher in the United States and Europe), and textiles (in which comparisons may be difficult owing to the Japanese firms being more chemical oriented and the U.S. companies being more purely clothing and retail oriented). Moreover, it seems that during the 1969–1986 period the rate of technological accumulation of the same Japanese firms rose significantly, while for European firms the rate remained steady, and for U.S. firms it actually fell. This can be judged from the observation that the level of U.S. patenting of these Japanese companies increased dramatically between 1969–1972 and 1983–1986, for European firms it rose moderately, and for the leading U.S. firms the numbers of patents granted actually fell.

[20] J.H. Dunning and R.D. Pearce, *The World's Largest Industrial Enterprises, 1962–1983* (Aldershot: Gower, 1985).

While this particular measure understates American achievements due to the rising propensity to patent abroad (U.S. company patenting also increased in Europe and Japan), all such measures suggest that Japanese firms tended to enjoy a superior rate of technological change.

As a result of these changes in the flow of new technology (*T′* above) there was a shift in the ranking of these groups of firms in terms of their patent to sales ratios (*T′/Q* above). This shift is illustrated in Table 1. For each group of firms the values of sales in 1972 and 1982 were aggregated and compared with their combined patenting in the United States in 1969–1972 and 1983–1986. There was a tendency for patent to sales ratios to fall simply because sales were measured in nominal and not real terms; due to the effect of the oil price rise this effect was especially noticeable in the coal and petroleum products industry.

Despite this, overall the average patent to sales ratio of Japanese firms increased slightly from 67.0 to 70.3. The U.S. company ratio fell substantially from 182.8 to 41.5. Therefore, by the early 1980s the average Japanese

TABLE 1 Ratio of U.S. Patents Granted to Global Sales (in billion dollars) of the leading U.S., Japanese, and European Industrial Firms in 1969–1972 and 1983–1986

	United States		Japan		Europe	
	1969–1972	1983–1986	1969–1972	1983–1986	1969–1972	1983–1986
Food products	43.2	7.6	19.6	9.4	16.0	7.4
Chemicals	465.0	111.2	173.4	133.7	245.9	82.9
Pharmaceuticals	246.6	74.9	155.2	76.5	248.8	84.8
Metals	106.0	21.3	24.4	24.0	58.0	24.0
Mechanical engineering	273.9	68.9	16.5	32.2	113.5	57.3
Electrical equipment	296.1	90.4	142.2	148.2	151.5	55.3
Office equipment	325.6	82.2	206.5	276.5	179.6	40.3
Motor vehicles	84.7	26.1	43.1	73.0	73.5	28.8
Textiles	25.7	7.8	67.1	60.5	31.4	10.2
Paper products	62.1	22.4	2.5	8.5	16.3	6.2
Printing and publishing	16.3	3.3	10.1	24.5	1.7	0.7
Rubber products	166.5	50.4	79.8	82.2	34.2	6.1
Nonmetallic mineral products	215.5	63.5	118.8	39.0	43.8	15.5
Coal and petroleum products	126.7	18.8	7.9	4.2	58.4	7.5
Total manufacturing	182.8	41.5	67.0	70.3	100.5	30.8

SOURCE: Data base on the world's largest industrial firms held at the University of Reading.

company's patent to sales ratio had risen above the U.S. equivalent, just as Japan's ratio of nondefense R&D to GDP rose above the U.S. level in the early 1970s. In fact, the catching up of the Japanese (*T'/Q*) ratio may well have happened at around the same time at both the firm level and the country level, given that U.S. patenting is a technology measure that is weighted in favor of U.S. firms. U.S. firms are likely to have a higher propensity to patent in the United States than are firms based elsewhere.

By 1983–1986, the average patent to sales ratio of the leading Japanese firms had risen above the U.S. company ratio in all industries except mechanical engineering, paper products, nonmetallic mineral products, and coal and petroleum products. U.S. firms were not very far behind, though, in food products, pharmaceuticals and metals. These are all branches in which U.S. firms had retained a reasonable rate of technological accumulation by international standards. Similarly, it is not surprising that the highest patent to sales ratios of Japanese firms (reaching around 150 patents per $1 billion of sales or greater) were obtained in the industries of their highest rate of innovation, that is electrical equipment and office equipment or computers. So the expected relationship between the rate of technological accumulation, growth, and the ratio of new technology to output seems to hold up not only at the level of national comparisons, but also when these are extended to the industry level. The innovative record of national groups of firms varies across industries according to their comparative advantage in technological activity.

The rate of technological change of Japanese firms has been greatest in the electrical equipment, office equipment and motor vehicles sectors, and in these industries they have experienced the fastest growth and increase in market shares. It is also feasible to examine the comparative advantage of firms within industries, as measured by their pattern of specialization in technological activity compared to other companies in the same industry. For this purpose consider firms in the industries with the highest levels of patenting: chemicals and pharmaceuticals, taken together, and electrical equipment and office equipment, taken together.

In the introduction the recent link between Japan's overall pattern of technological specialization (RTA) and the structure of technological opportunities (or the growth of patenting) was demonstrated. It is possible to carry out a similar exercise at the industry level, from an analysis of the patenting of firms in the chosen industry considered separately. To this end, total industry patent growth between 1969–1972 and 1983–1986 was regressed on the RTA of Japanese firms in the same industry at the start of the period. This depends upon the distinction between the classification of firms by the industry for which they produce and (in any industry) the classification of their patenting by types of technological activity. Denoting the growth of total patenting in a branch of technological activity i by

GT_i, and Japanese RTA by RTA_i, the form of the cross-section regression in each industry was as follows:

$$GT_i = \alpha_o + \beta_o\, RTA_i + \varepsilon_{oi}$$

As in Figure 1, patents were allocated to one of 33 types of technological activity (sectors i), but branches were excluded if firms in the industry in question had no activity in that sector. This left 25 sectors in the chemical and pharmaceutical industry, and 27 technological sectors in the case of firms manufacturing electrical and computing equipment.

As shown in Table 2, the competitive strength of Japanese firms in terms of the beneficial nature of their technological specialization is clearly more evident in the electrical and office equipment industry than it is in chemicals and pharmaceuticals. In the electrical industry the RTA of Japanese firms in 1969–1972 was positively and significantly related to the distribution of subsequent patent growth in the industry as a whole from 1969–1972 to 1983–1986. In other words, Japanese firms specialized in fields in which, at an industry level, technological opportunities were at their greatest.

In the electrical equipment industry the fields of greatest patent growth and high Japanese RTA were road vehicles and engines, and image and sound equipment. This is indicative of a crucial area of Japanese success under the new technology paradigm. Under a new paradigm pervasive technologies gradually help to transform industries outside those in which they were originally developed. In this case under Japanese leadership the infusion of new electronic technology reinvigorated the motor vehicle industry, which had previously been regarded as a "mature" and noninnovative industry. The vehicles industry now symbolizes the transition between paradigms: from the production of vehicles intensive in their use of energy by scale-intensive methods, towards customer-designed vehicles produced by computerized systems. The major Japanese electrical equipment producers were geared up for this new technological opportunity at an early stage.

TABLE 2 The Cross-Sectoral Regression of Total Industry Patent Growth from 1969–1972 to 19832–1986 on the RTA of Japanese Firms in the Same Industry

	$\hat{\alpha}$	$\hat{\beta}$	t	t
Chemicals and pharmaceuticals	12.189	8.164	0.53	0.50
Electrical and office equipment	-22.777	52.310	-1.11	3.28[a]

[a] Denotes coefficient significantly different from zero at the 1% level.

In the chemical industry the largest Japanese firms also specialized in electrical technology. The positive association between Japanese RTA and patent growth can be related to the fast growth in the technological activity of the major chemical companies in computers and image and sound equipment (presumably as means of reorganizing chemical production plants, with computerized control technologies that met their own specific objectives). However, the fit between Japanese RTA and patent growth was not significant as Japanese chemical firms had no specialization in the other leading fields of technological opportunity in the industry; namely, in agricultural chemicals, pharmaceuticals and biotechnology.

So the specialization of Japanese firms gave a general impetus to their overall rate of technological accumulation, but the effectiveness of this varied across industries. It has been at its strongest in industries in which technologies can be most clearly related to electrical and computing systems. There is another way of viewing this connection, however. As the new paradigm has taken shape, so the composition of technological opportunities has been gradually changed in each industry. These opportunities have steadily shifted in favor of the key fields of the new paradigm, in which high growth has already been experienced in the leading industries, as spillover benefits from these industries and the potential for new forms of technology fusion begin to influence other industries.

If Japanese firms have led these changes, then they can be expected to have been the first to have taken advantage of the new opportunities created in a broad range of industries. To test this, the growth of patenting across different fields of activity was compared in two different periods. Considering again firms in the electrical and chemical industries, total industry patent growth between 1978–1982 and 1983–1986 was regressed on the growth of patenting by Japanese companies in the same industry between 1969–1972 and 1973–1977. Denoting the growth of Japanese firm patenting in the technological field *i* by GJ_i, and using subscript *t* and *t-1* for the later and earlier periods respectively, the simple cross-section regression was

$$GT_{it} = \alpha_1 + \beta_1 GJ_{it-1} + \varepsilon_{1it-1}$$

Excluding sectors with very low levels of patenting left 24 branches of activity in the chemical case and 23 in the electrical and computing equipment industry.

The results are reported in Table 3, and they illustrate a further element of the technological leadership already being exercised by Japanese firms. Even in the chemical industry the fields in which Japanese companies concentrated their efforts in the early 1970s were significantly related to those that were to become the major areas of technological opportunity in the industry in the early 1980s.

Of course, this might only mean that technological opportunities were greatest in the same branches of activity in both periods. There is an element of truth in this in the electrical and computing equipment industry. However, Japanese firms still demonstrated some leadership in taking up activities within the electrical industry at this time. The pattern of patent growth in Japanese companies early in the period provided a better explanation of the distribution of total patent growth at the end of the period than did total patent growth at the start of the period. Total electrical industry patent growth from 1978–1982 to 1983–1986 was positively correlated with the equivalent Japanese patent growth from 1969–1972 to 1973–1977 at the 5 percent level (see Table 3), but it was correlated with total industry patent growth in the earlier period only (just) at the 10 percent level.

Table 3 The Cross-Sectoral Regression of Total Industry Patent Growth from 1978–1982 to 1983–1986 on the Growth of Patenting by Japanese Firms in the Same Industry from 1969–1972 to 1973–1977

	$\hat{\alpha}$	$\hat{\beta}$	*t*	*t*
Chemicals and pharmaceuticals	-26.656	0.180	-3.14[a]	4.47[a]
Electrical and office equipment	-13.531	0.136	-1.83[b]	2.57[c]

[a] Denotes coefficient significantly different from zero at the 1% level.
[b] Denotes coefficient significantly different from zero at the 10% level.
[c] Denotes coefficient significantly different from zero at the 5% level.

In the chemical industry, though, there is no correlation at all between total patent growth in the two periods; the distribution of technological opportunities underwent a substantial change. This is consistent with the view that a new technology paradigm begins by affecting leading industries before moving out to influence others. While the new fields of technological opportunity had already become fairly settled in the electrical industry between the 1970s and 1980s, opportunities in the chemical industry began to shift at that time. Japanese firms seem to have helped lead this switch.

In the electrical equipment industry the fields of high patent growth in both 1969–1977 and 1978–1986 have already been mentioned. These are road vehicles and engines and image and sound equipment. Japanese firms were not only specialized in these areas in 1969–1972 (as commented on above), but they also witnessed very fast growth in the same areas through to 1973–1977, so that the extent of their specialization (RTA) in these fields actually increased.

In the chemical and pharmaceutical industry, the technological activities in which Japanese companies expanded their interests fastest, to be followed subsequently by their competitors, were in computers, image and sound equipment, and electronic communications. This illustrates how the effects of the new technology paradigm had begun to influence the pattern of technological change in the chemical industry by the early 1980s. The leading Japanese chemical companies, perhaps drawing on collaborative arrangements with the Japanese electrical industry, were in the forefront of initiating this new development. The change in technology paradigm may have assisted the rate of technological accumulation of Japanese firms in some industries more than others (in electrical equipment more than in chemicals), but it has given Japanese companies some impetus in most industries.

SOME CONCLUSIONS AND SUGGESTIONS ON THE IMPLICATIONS FOR JAPAN'S FUTURE TECHNOLOGICAL COMPETITIVENESS

On this subject it is perhaps rather dangerous to speculate too much about the future. However, some suggestions do emerge if bets about the future must be made. The most significant is that the rate of growth of Japanese industry and of the leading Japanese firms is likely to continue to exceed the equivalent U.S. growth so long as the Japanese sustain a higher rate of technological change; and the Japanese rate of technological accumulation is likely to remain higher so long as the now prevailing technology paradigm continues in place. The Japanese national system of innovation and the accompanying pattern of technological specialization of her firms have come to represent the very expression of this paradigm. By contrast, U.S. institutions remain to some extent locked into structures associated with a previous era of technological opportunities, just as British institutions had been at the turn of the century.[21]

As technological change is cumulative and incremental, organizational routines adapt only slowly, and institutional structures can only change gradually, countries and firms become locked into some technological course. The distribution of technological opportunities then favors some countries and firms rather than others. In the near future the current technology paradigm with its particular spread of opportunities is likely to be consolidated further rather than reversed, and this will work to the advantage of the Japanese. The changes that will occur in the composition of technological opportunities are likely to be mainly of an incremental kind, moving from the fast growth fields of the 1980s into related areas. Japanese firms are likely to lead such incremental shifts.

So long as they do, Japan will open up a new lead not only in its rate of technological accumulation but also in its overall level of technological capability. The model described above suggests that there is no relationship

[21] Cantwell, op. cit., footnote 12.

between the proportional rate of technological accumulation (and hence growth) and the current level of technological capability. Just as there was no necessary reason why the United States had to have the highest rate of innovation when it had the largest technological capability, so now there is no reason why Japan should not continue to sustain its high rate of technological change with the greatest overall level of capability. It is only likely to fall back if there is another change in the technology paradigm that provides a new window of opportunity to others on a different technological course.

This offers a perspective at odds with those who have claimed that Japan's high rate of innovation was due to having a lower level of technological capability than the United States, offering the scope to catch up rapidly through the import and adaptation of foreign technology. A rather more sophisticated variant of this argument is that the United States still retains the leadership in science even if she has lost it in technology, so Japan remains dependent on her ability to commercialize U.S. scientific achievements.

These contentions are misleading insofar as they rely on what has recently been called (by Rosenberg, among others) the linear model of technological development. In the linear model, there is a unidirectional causal chain that runs from scientific advance to technology pioneered by an innovative leader, to diffusion to a wider circle of firms and to other industries. In fact, there is more likely to be a regular interchange between the problem-solving activities of different companies, combining to generate a series of complementary technological improvements. In the process they all contribute to an underlying stock of generic knowledge that is to some extent held in common. Even the direction of scientific advance comes to depend upon the issues raised through technological problem-solving activity, or more directly upon technology itself (as in the case of the creation of new and more precise scientific instruments). So if Japanese technology is dependent upon U.S. science, so too is U.S. science dependent upon Japanese technology.

To put matters another way, the distinction between innovation and imitation is blurred to the point where it may be analytically unhelpful. Japanese firms were more successful in their imitation than others that lay the same distance behind the "technology frontier" because this imitation went alongside their own high rate of technological innovation. This is illustrated by the study of patent citations by Narin and his colleagues, who have shown that Japanese patents have on average been of higher quality than others; they do not simply represent minor adaptations. Since, as outlined in the introduction, technology is localized, imitation is often just as costly as innovation, and it is sometimes more so (where the imitator begins from a technological base that is poorly related to the field in question, or where it is operating in a less helpful environment).[22] The imitation of related technologies supports the cumulative development of the firms' own technology; imitation and innovation are complements rather than alternatives.

The interplay between imitation, innovation, and science and the increased importance of basic R&D in the new paradigm help to explain why Japanese firms have been investing heavily in basic research to enhance the further development of their strengths in production engineering, computerized systems and new organizational methods. Firms carry out basic research partly to increase their ability to monitor their external environment, and to help them identify opportunities that might otherwise be missed.[23] Although generic knowledge is not itself responsible for lasting differences in technological competence between countries and firms, a capacity to generate and understand such knowledge helps to support local competence.

Moreover, even though in the core fields of the new technology paradigm Japan's absolute level of technological capability may exceed that of the United States, the scope for Japanese imitation is not over. Since technological development is localized and differentiated, the course followed by Japanese firms is to some extent different from the path of U.S. firms in the same industry. Therefore, they still have much to learn from one another, whether through agreements for technological cooperation or otherwise. This helps to explain the trend toward international production by the leading multinationals in foreign centers of excellence. The U.S.-located affiliates of Japanese firms provide their parent companies with a stream of complementary technologies, derived from the local characteristics of U.S. production. [24] European firms in the United States and U.S. firms in Europe have followed similar strategies for international technological development for some years.

Mutual strategies for imitation do not in themselves provide a threat to an innovative leader. Firms that sustain a higher rate of technological change will also tend to have a greater capacity to imitate others where appropriate and to build upon opportunities in fields related to their own. It may well be in the Japanese interest to help to promote a wider diffusion (through localized adaptation) of the technologies they have pioneered. This may improve the positive interaction between U.S. and Japanese firms,

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[22] E. Mansfield, M. Schwartz, and S. Wagner, "Imitation Costs and Patents: An Emipirical Study," *Economic Journal*, vol. 91, no. 4., 1981.

[23] W.M. Cohen and D.A. Levinthal, "Innovation and Learning: The Two Faces of R&D," *Economic Journal*, vol. 99, No. 3., 1989 and N. Rosenberg, "Why Do Firms Do Basic Research (With Their Own Money)?" *Research Policy*, vol. 19, no. 2., 1990.

[24] Cantwell, op. cit., footnote 15 and B. Kogut and S.J. Chang, "Technological Capabilities and Japanese Foreign Direct Investment in the United States," *Review of Economics and Statistics*, vol. 73, no. 3, 1991.

allowing them both to raise their rate of technological accumulation. While mutual imitation between U.S. and Japanese firms, whether through cooperative agreements or otherwise, increases their rates of technological change, it will not necessarily affect the differential between them. However, in his contribution to this volume Professor Nelson suggests that such greater international interchange will also reduce the differential in rates of innovation between countries or national groups of firms, but the basis for this argument is essentially that in the close combination of imitation and innovation there has been a shift towards imitation and intercompany linkages. The growth in cross-border exchanges between firms, formalized in some cases by strategic alliances, may be partly explained by the increasing interrelatedness between formerly separate types of technology, such that imitation becomes an even greater mutual benefit or necessity.

Although Japanese firms are likely to continue to sustain an overall rate of technological accumulation higher than their major rivals in the immediate future, this will vary across industries. They are likely to continue to lead in electrical equipment and motor vehicles, but they will not necessarily do so in chemicals, even if their rate of technological change has risen relative to their competitors (the new paradigm has had an effect). Freeman has discussed the likelihood of Japanese firms further raising their rate of technological progress in the chemical industry.[25] Whether they manage this or not, it seems unlikely that the overall pattern of technological specialization of Japanese companies will change too dramatically. Given the cumulative nature of technological change, they are likely to achieve more success in building upon their core strengths in electronic-related technologies than they are liable to accomplish in a new and largely unrelated field such as biotechnology.

Very little has been said so far about technology policy. This is partly because a great deal has been written on Japanese technology policy elsewhere, and on its role in helping to ensure Japan's leadership in the new technology paradigm.[26] Japan has for some years emphasized long-term industrial policies rather than policies of short-term macroeconomic management. She has emphasized investment in education, training, and the scientific and allied infrastructure. The Japanese government has regularly collaborated with industry to try and ensure that the longer term market forces they have identified work to their advantage. This compares favorably with the prevalent attitude in the United States and Britain especially in the 1980s, which has held that governments should steer completely clear

[25] C. Freeman, "Technical Innovation in the World Chemical Industry and Changes of Techno-Economic Paradigm," in C. Freeman and L.L.G. Soete, eds., *New Explorations in the Economics of Technical Change* (London: Frances Pinter, 1990).

of private corporate decisions, and allow markets and firms to operate entirely independently. The result is that where strategic government support for industry is required to foster technological development, the U.S. government may come to pick up the signals to this effect only late in the day:

> "American government officials and businessmen negotiating economic matters feel at a great disadvantage because Japanese officials are much better informed, not only about Japanese companies, but often about American companies."[27]

Economists and policy advisors tend to overemphasize the efficacy of their policy recommendations, since it is in this way that they persuade their audience and ultimately the policymakers. It seems unlikely that through policy changes alone the United States could raise the rate of technological advance in her industry to Japanese levels. The structure of institutions and local technological competence is different in the United States, and it is simply much more costly for her to undertake the deep shift required to bring her closer to a structure that better fits the new technology paradigm. However, this is not a recipe for doing nothing, as under these conditions the U.S. position may deteriorate further. With the appropriate technology policy; support for science, education, and training; encouragement of new organizational structures and industrial relations systems; and new forms of association between finance and industry, the costs of the transition to the new technology paradigm will be reduced, the rate of technological change will rise, and longer-term benefits will follow. This is one of the lessons of the Japanese experience.

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[26] Freeman, op. cit., footnote 6.
[27] E.F. Vogel, *Japan as Number One* (Tokyo: Turtle, 1980) cited in Freeman, op. cit., footnote 6.

Japanese Control of R&D Activities in the United States: Is This Cause for Concern?

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INTRODUCTION

Since the middle 1980s, the research and development expenditures of Japanese-controlled firms operating in the United States have significantly increased. This is true not simply in absolute terms but also in relative terms; that is, the percentage of total R&D expenditures in the United States accounted for by Japanese-controlled firms has increased dramatically. This comes at a time when total nondefense R&D expenditures by the United States as a percentage of national income have not kept pace with similar expenditures (again as a percentage of national income) in Japan.

Is the rise in U.S. R&D expenditures accounted for by Japanese firms a cause for major concern from a U.S. interests perspective? This issue is examined in this paper. The next section details some of the salient facts. The final section probes whether or not these facts are cause for worry.

THE RISE IN JAPANESE CONTROL OF U.S. R&D

During the second half of the 1980s, Japanese direct investment in the United States increased dramatically (Table 1), reflecting rapid increase in control of U.S. business activities by Japanese multinational corporations. During the early years of this surge, most of this investment was of the "green fields" variety (i.e., the creation of entirely new business activities in the United States), but beginning in 1987, Japanese direct investors moved increasingly towards acquisition of existing U.S. firms as the primary mode of new entry.

TABLE 1 Japanese Direct Investment in the United States, 1984–1990 (in million dollars)

Year	Flow During Year	Position at Year End
1984	4,374	16,044
1985	3,394	19,313
1986	7,268	26,284
1987	8,791	34,421
1988	17,287	51,126
1989	17,425	67,319
1990	17,336	83,498

SOURCE: Bureau of Economic Analysis, U.S. Department of Commerce, compiled from August issues of *Survey of Current Business*, various years.

The surge in Japanese direct investment in the United States coincided with a general perception on the part of many U.S. business leaders and economists that U.S.-owned business firms operating in advanced technology industries were becoming significantly less competitive relative to their Japanese rivals and that this loss of competitiveness was not a phenomenon that could be corrected via macroeconomic adjustments such as revaluation of the yen. Rather, it was widely perceived that the loss was due to some combination of factors such as declining rates of R&D expenditure in the United States relative to Japan, "short termism" and other managerial failures by U.S. business leaders, low U.S. rates of domestic capital formation, flagging U.S. educational performance, and a poor policy environment for U.S. technology.

Figures 1 and 2 provide some supporting evidence for the position that U.S. competitiveness is falling relative to Japan and that this is due in part to falling relative expenditures on R&D. Total U.S. R&D expenditure as a percentage of the gross national product (GNP) was significantly higher than corresponding percentages in Japan or Germany during the early 1970s, but by the middle 1980s both nations were outperforming the United States by this measure. This is true in spite of the fact that total U.S. R&D expenditures as a percentage of GNP were at a minimum during the late 1970s and have risen since then. Otherwise put, the trend in R&D expenditure as a percentage of national product has been upward in all three countries, but this percentage has risen significantly faster in both Germany and Japan than in the United States. Because GNP has grown significantly faster in Japan than in the United States, total R&D expenditures in Japan have grown even faster relative to those in the United States than the figure would suggest.

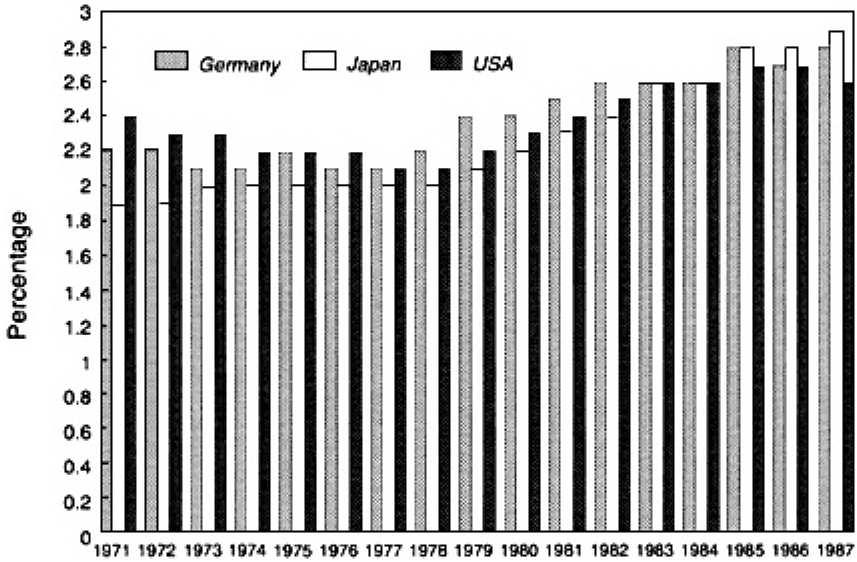

Figure 1 G-3 R&D expenditures as % of GNP, 1971–87. Source: Prepared at Institute for International Economics from U.S. National Science Foundation base data.

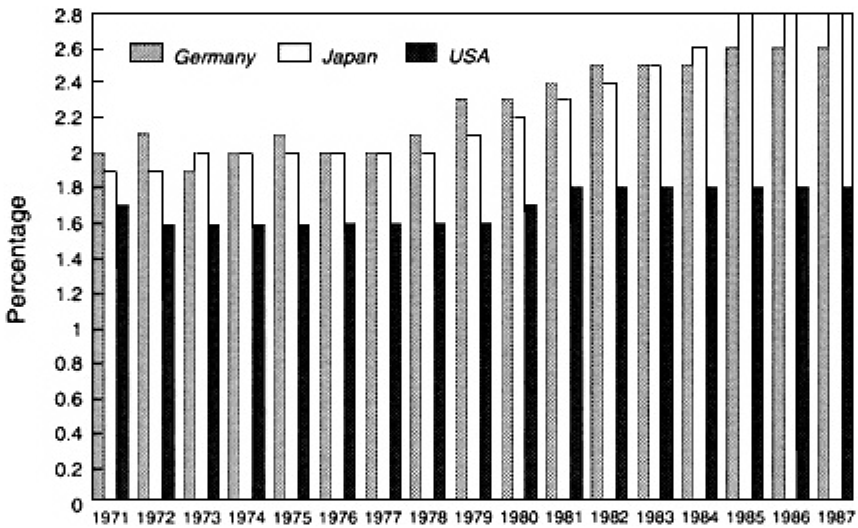

Figure 2 G-3 Nondefense R&D expenditure as % of GNP, 1971–87. Source: Prepared at Institute for International Economics from U.S. National Science Foundation base data.

A much higher percentage of R&D expenditure in the United States is undertaken for defense than in either Japan or Germany. Figure 2, indicating *non*defense R&D as a percentage of GNP, illustrates the difference vividly. Even in 1971 this percentage was significantly higher for both Japan and Germany than for the United States, and the relative difference has grown considerably since then. Unlike total R&D as a percentage of GNP, in the United States nondefense R&D as a percentage of GNP has hardly grown at all since the late 1970s; and indeed, from 1983 onward, if anything the trend is slightly downward. Thus, virtually all of the U.S. increase in total R&D as a percentage of GNP during the 1980s has been defense related. By contrast, nondefense R&D expenditure as a percentage of national product has risen markedly in both Japan and Germany since the late 1970s. In the case of Japan, the rise has been dramatic, while the rise for Germany is significantly less than for Japan although still marked.

The data portrayed in Figures 1 and 2 go only through 1987, but they are, alas, the most recent available. Unfortunately, there is little to suggest that the relative U.S. position has improved since that year.

During the 1980s, as already noted, Japanese direct investment in the United States rose dramatically, and with this has come a sharp rise from a level of almost nothing in the research and development done in the United States by Japanese-controlled corporations. The rise in control of domestic business entities by Japanese firms is depicted in Figure 3, which indicates the foreign direct investment (FDI) stock of U.S. affiliates of Japanese firms as a percentage of the net worth of U.S. nonfinancial corporations. It should be noted that FDI is a balance of payments flow concept that roughly measures the total change in the foreign investors' share of the net worth at historic cost of U.S. enterprises deemed to be under the control of foreign investors. The cumulative stock of these flows (the "foreign direct investment position of the United States") is thus the total current value of the foreign share of this net worth measured at historic value. (In 1991, the Department of Commerce began issuing figures representing estimates of the current market and replacement values of this stock.) This stock includes both (paid-in) investment and retained earnings. It also includes the net indebtedness between the U.S. affiliate and its foreign parent, a figure considered by the Department of Commerce as near equity.

Thus, the FDI stock figures that are the numerators for the bars shown in Figure 3 are (roughly) measures of net worth held by Japanese investors in activities they control in the United States. Thus, the ratios in this figure roughly compare "apples to apples," as opposed to many other presentations of the relative importance of FDI where the comparisons are "apples to oranges" (e.g., the ratio of FDI to GNP). As can be seen from the figure, the percentage of net worth of U.S. nonfinancial corporations controlled by Japanese direct investors increased eighteenfold from 1977 to 1989—a truly spectacular increase. But at the same time, even at the end of 1989, the total percentage of net worth of U.S. nonfinancial corporations held by Japanese direct investors, 1.8 percent, was really still quite low. At the Institute for International Economics we have estimated that this percentage rose to something like 2.1 percent at the end of 1990. In 1991, the rate of increase of this percentage appears to have slackened substantially, although it is too early to say this for sure because the relevant data is incomplete and subject to revision.

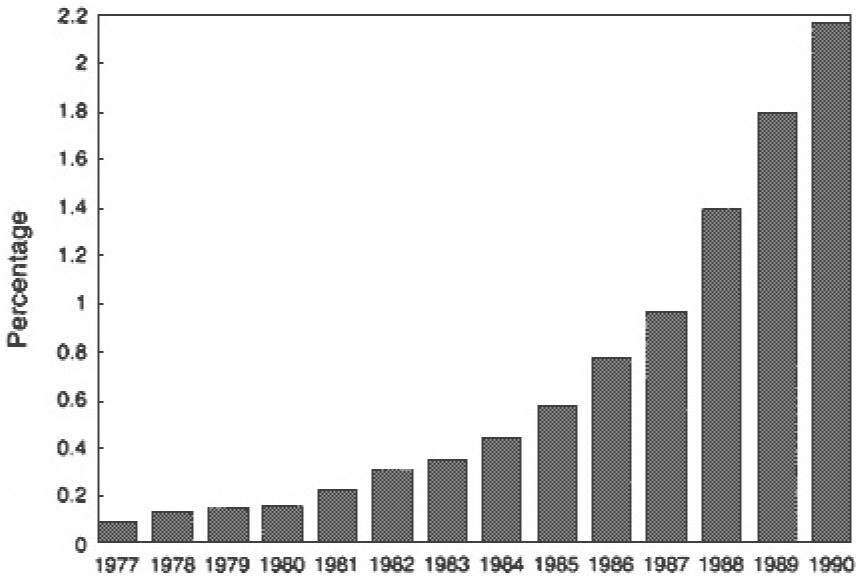

Figure 3 FDI stock of U.S. affiliates of Japanese firms as % of U.S. non-financial corporations, 1977–1990. Source: Prepared at Institute for International Economics from U.S. Department of Commerce, Bureau of Economic Analysis, base data.

The percentage of U.S. GNP accounted for by domestic U.S. affiliates of Japanese firms also grew dramatically during the 1980s. By 1987 (the latest year for which data currently are available) this percentage was about 0.34 percent, up from about 0.13 percent in 1977 (Figure 4). The reader will note that the percentage of U.S. GNP accounted for by U.S. affiliates of Japanese firms in 1987 is much lower than the percent of U.S. nonfinancial corporate net worth held by Japanese direct investors; the latter is shown on Figure 3 to be about 1 percent in that year. There appear to be two reasons for the difference in these two measures. First, the nonfinancial corporate sector accounts for considerably less than the whole of the

U.S. economy, and most Japanese FDI is in the nonfinancial corporate sector. Thus, a measure of the Japanese presence in the corporate sector is bound to be much higher than a measure of the Japanese presence in the economy as a whole. Second, the figure reported by the Bureau of Economic Analysis of the U.S. Department of Commerce for value-added by U.S. affiliates of Japanese corporations in 1987 (the numerator for the percentages in Figure 4) is a preliminary one that is subject to revision, and this author suspects that it is too low; my guess is that 0.4 to 0.45 percent would be more accurate.

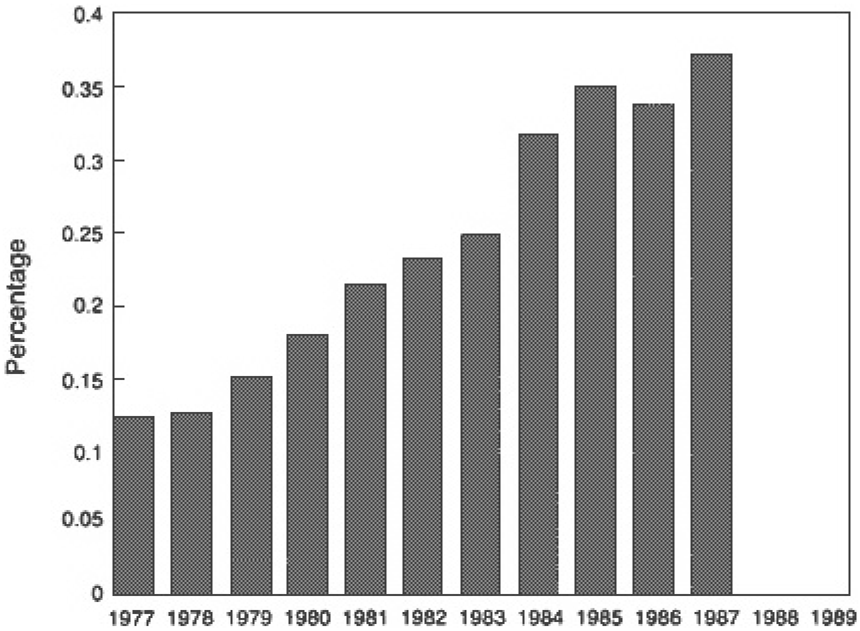

Figure 4 Value-added of U.S. affiliates of Japanese firms as % of U.S. GNP. Source: Prepared at Institute for International Economics from U.S. Department of Commerce, Bureau of Economic Analysis, base data.

Whatever the case, the percentage of U.S. GNP accounted for by domestic firms controlled by the Japanese was less than one half of 1 percent in 1987, not an enormous number. This percentage has doubtlessly increased since then, given considerable additions to the amount of Japanese FDI in the United States. Even so, however, it is very safe to say that at the moment, U.S. affiliates of Japanese firms account for less than I percent of U.S. GNP; the author's best guess is that this figure is about three-fourths of 1 percent.

Along with Japanese control has come a significant increase in R&D activity undertaken by domestic affiliates of Japanese firms. Total annual R&D expenditures by such affiliates are detailed in Figure 5. These expenditures increased by 2.5 times just between 1987 and 1989. The years 1988 and 1989 were characterized by large-scale takeovers of U.S. firms by Japanese investors, and exactly how much of the increase in these expenditures is accounted for by takeovers (and hence transfer of R&D activity from domestic to Japanese control) cannot, alas, be determined directly from the data publicly available. While much of the increase is doubtlessly due to these takeovers, it is not likely that all of it is, a case supported by indirect evidence to be presented shortly. As previously noted, prior to 1987 most Japanese foreign direct investment in the United States entered in the form of green fields investment rather than acquisition (see Table 2), but acquisitions have been predominant from 1987 onwards.

As might be expected given the evidence already presented, the fraction of total U.S. R&D accounted for by U.S. affiliates of Japanese firms has also risen dramatically in recent years. Figure 6 presents relevant data; the reader should note that the denominator in this figure is total *company*-

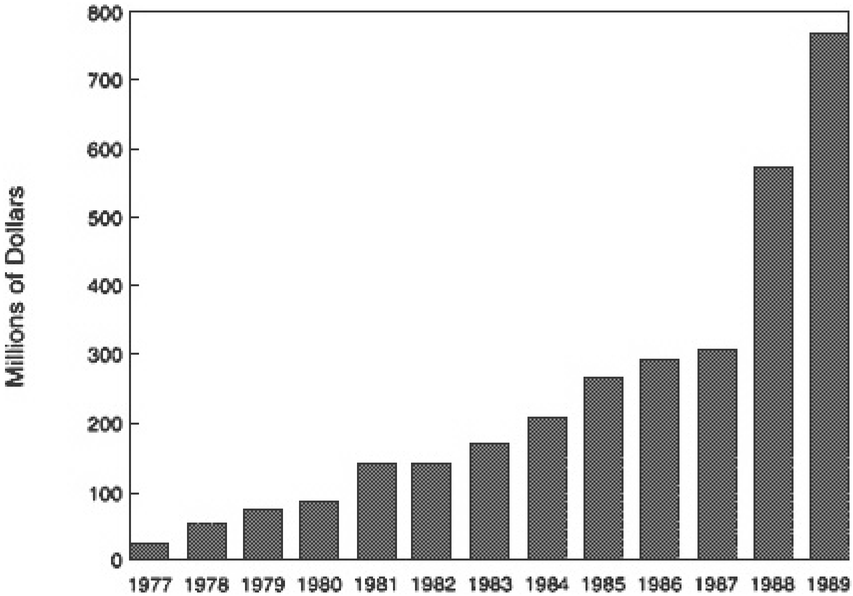

Figure 5 R&D of U.S. Affiliates of Japanese firms. Source: Prepared at Institute for International Economics from U.S. Department of Commerce, Bureau of Economic Analysis, base data.

TABLE 2 Japanese Acquisitions and New Establishments in the United States, 1987–1989 (in million dollars)

	1987	1988	1989	1990
Acquisitions	3,340	12,233	11,204	15,875
New establishments	3,666	3,956	6,206	4,584

Source: Bureau of Economic Analysis, U.S. Department of Commerce, *Survey of Current Business*, May 1991.

funded R&D, not all U.S. R&D. The R&D of U.S. affiliates of Japanese firms jumped from about 0.5 percent of total U.S. company funded R&D in 1987 to about 1.1 percent in 1989. This increase of 2.2 times was less than the increase in the absolute amount of R&D done by these affiliates (2.5 times), reflecting the fact that the total amount of R&D done by companies did in fact increase over these two years.

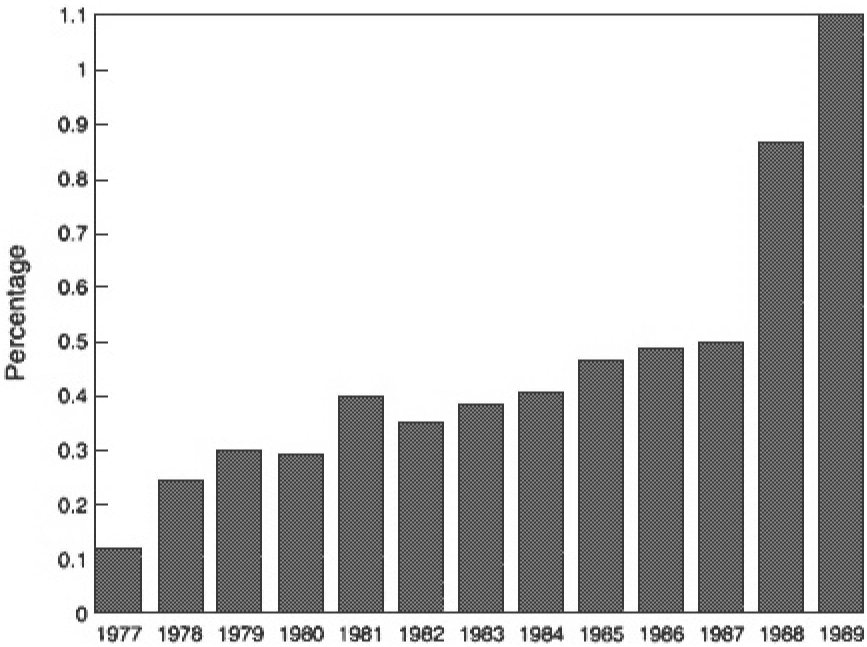

Figure 6 R&D of U.S. affiliates of Japanese firms as % of total U.S. R&D (company-funded). Source: Prepared at Institute for International Economics from U.S. Department of Commerce, Bureau of Economic Analysis, base data.

TABLE 3 Measures of Performance of Manufacturing Subsidiaries of Non-U.S. Parent Firms by Country of Origin of Parent and of All U.S. Manufacturing Industry, 1987

Measure/ Country of Origin	Value Added per Worker	Compensation per Worker (thousand dollars)	R&D per Worker
United Kingdom	44.5	28.5	1.72
Germany	49.2	36.5	5.23
Netherlands	43.7	34.7	NA
France	47.5	35.5	3.16
All Europe	45.9	32.0	3.17
Japan	49.8	35.1	2.88
All nations	48.6	32.9	3.61
All U.S. manufacturing	46.0	31.1	2.87

SOURCE: Calculated by Institute for International Economics using base data from the Bureau of Economic Analysis, U.S. Department of Commerce.

As is indicated in Table 3, by two measures, value-added per worker and compensation per worker, U.S. affiliates of Japanese-controlled firms in the manufacturing sector outperformed affiliates of firms from all other nations in 1987, the most recent year for which these data are available. This might be because of selection bias (i.e., Japanese firms might be operating in more capital-intensive industries than firms from other nations, where output per worker tends to be high). The data do not permit testing of whether or not selection bias is significant, unfortunately. By the measure of research and development per worker, however, U.S. manufacturing affiliates of Japanese firms do not compare favorably with U.S. manufacturing affiliates of continental European firms, but do outperform the affiliates of U.K.-based firms. Given the growth of R&D in the United States by affiliates of Japanese firms since 1987, the Japanese figure has almost surely risen since then. We estimate research and development per worker by U.S. affiliates of Japanese firms in the manufacturing sector now to be about $4,000 per year.

The percentage of net worth of nonfinancial corporations accounted for by Japanese FDI increased by 1.9 times between 1987 and 1989 (i.e., was about 90 percent higher in 1989 than in 1987; see Figure 3), whereas R&D done by U.S. affiliates of Japanese corporations as a percentage of total company-funded U.S. R&D was (from the figures just cited) about 120 percent higher in 1989 than in 1987. If the ratio of R&D expenditures to net worth were constant across all companies (it of course is not!), these numbers would suggest that about three-fourths of the jump in R&D expenditures by these affiliates between 1987 and 1989 is accounted for by acquisitions (the three-fourths figure is calculated as the ratio of the net worth ratio increase to the R&D ratio increase, or 90/120) and hence about one-fourth came from other sources, notably establishment of new R&D operations under Japanese control or expansion of such operations already under Japanese control in 1987. Impressionistic evidence suggests however that the R&D intensity of the major Japanese acquisitions during 1987–1989 (which included CBS Records, Columbia Pictures, Rockefeller Center, etc.) was if anything less than that of existing Japanese-controlled activities in the United States in 1987 (which included the major automotive investments plus significant operations in the electronics sector), and hence the author's guess is that the three-fourths figure is too high and the one-fourth figure too low; the author's "guesstimate" is that perhaps as much as one-third of the total increase in Japanese-controlled R&D in the United States between 1987 and 1989 was due to creation of new R&D operations or expansion of existing ones, whereas something like two-thirds of this increase represented transfer of existing R&D operations from domestic to Japanese ownership. These figures should be taken for what they are, that is, rather crude estimates and not precise measurements.

Whatever the case, it is clear from Figure 6 that as spectacular as the rate of increase of R&D done in the United States by Japanese-controlled firms has been, the annual total remains a small fraction of total U.S. company-funded R&D. Also, the amount of this R&D is remarkably commensurate with the overall level of Japanese-controlled activity in the economy. About 1.8 percent of nonfinancial corporate net worth is held by Japanese foreign direct investors, and about 1.1 percent of company funded R&D is done by U.S. affiliates of these investors. Given the author's guess that these affiliates account for about 0.75 percent of U.S. GNP, it would appear that they are making a slightly larger contribution to the nation's R&D effort than to the U.S. national product.

There at present exists remarkably little data on precisely where Japanese direct investors are placing their R&D dollars and what their motivation is for doing so. What evidence that does exist does not always tell the same story. For example, one story often told by critics of Japanese FDI is that most R&D done by U.S. affiliates of Japanese firms is of the "commercial listening post" variety. By this account, this R&D is not really R&D in the normal sense of the word, but rather is some combination of market research (so that products actually engineered in Japan can be tailored to the U.S. market) and industrial espionage. But another story often told by these critics is that Japanese firms are buying up small high technology ventures wherein important state-of-the-art technologies are being developed. The usual assumption here is that the basic motive of the investor is to snatch away the technology and transfer it quickly back to Japan. This latter may indeed happen, but the large increases in the expenditures of U.S. affiliates of Japanese corporations detailed in Figure 5 argue against this being the story of the typical Japanese takeover; the fact is that these expenditures have been growing very rapidly, and this is not consistent with a story of Japanese corporations buying U.S. high tech ventures for the sole purpose of gutting them or "hollowing them out."

A rather opposite story has been told to this author by a number of Japanese business persons and economists. This is that the ultimate intent of many large Japanese firms operating in the United States is to create major R&D centers here, with an emphasis on basic and precommercial research. The rationale for this is that whereas Japan excels in product design and manufacturing innovation, it still significantly lags the United States in fundamental scientific disciplines. Comparative advantage, if one likes, resides in U.S. basic science and technology, but in Japanese applied technology. Unable as in the past to be able to count upon licensing and other indirect means of acquiring precommercial technologies from the United States, major Japanese firms will now seek to obtain these directly by controlling the relevant activities in the United States.

Whatever the logic of this position, it is not entirely clear that recent trends actually have been in this direction either. Press reports have appeared pertaining to U.S. R&D activities of the large, vertically integrated Japanese electronics firms such as NEC, Fujitsu, Hitachi, Sony—precisely the firms most likely to perform large-scale basic research.[1] These activities to date appear (on the basis of largely anecdotal evidence) to be quite modest in scale. The U.S. laboratories of such firms, for example, employ many fewer employees than do the laboratories in Japan. Modest scale at the level of the individual firm is, of course, consistent with the data presented above, indicating an overall Japanese R&D presence in the United States of modest scale albeit growing rapidly. But, correspondingly, the U.S. laboratories of most Japanese firms are quite new, and in some cases they appear to be building capabilities quite consistent with the "focus on

[1] The basis for claiming that U.S. R&D activities under Japanese control are moving towards performing more basic R&D is largely anecdotal: a number of news reports have appeared indicating such a move (e.g., see "Japanese Labs in U.S. Luring America's Computer Experts," *The New York Times*, November 11, 1990; "Several Japanese Corporations Establish New Labs in United States," *Physics Today*, February 1991) and interviews conducted by this author supported the contention. However, a survey by Lois S. Peters ("Technology Strategies of Japanese Subsidiaries and Joint Ventures in the United States," working paper, Center for Science and Technology Policy, Rensselaer Polytechnic Institute, 1991) suggests that of the firms surveyed that performed R&D, "despite articles to the contrary implying extensive basic research conducted by American arms of Japanese companies . . . most of [this research] is in support of existing manufacturing operations and is applied more in the cast of technical support than of technological development."

basic research story." Whether they will grow into major basic R&D facilities is an issue that only time can resolve.

Creation of basic R&D operations in the United States is not wholly inconsistent with listening post activity.[2] The reason why has to do with the fact that the results of basic research are not necessarily manifested in commercial benefits that accrue directly to the organization that performs the research, but rather that these results take the form of new knowledge that must be further developed before tangible commercial benefits accrue to anyone. The knowledge itself can rarely be retained within a single organization; rather, it diffuses from the organization via modes such as scholarly articles and informal exchanges between research personnel at professional meetings. The commercialization of the knowledge might then take place within some other organization rather than the one that actually performed the initial research. The key idea is that in order to avail itself of such knowledge, an organization must both be plugged into the network of entities that generate basic knowledge and possess a minimum set of internal capabilities necessary to recognize potentially valuable information and to internalize this information in a way that can lead to commercial opportunity.

By this account, basic R&D activity by any firm (and not just Japanese-controlled ones!) serves to some extent as a listening post. The activity serves not simply to generate new knowledge that is used exclusively within the firm, but also to pick up and further develop new knowledge that is generated within other organizations. Clearly, for this latter function to be effective, an organization must actually be generating new knowledge as well as tapping in on the new knowledge generated by other organizations. But it is entirely plausible that basic R&D activities simultaneously are generators of new knowledge and receivers of other new knowledge generated elsewhere.

Thus, basic R&D activities of Japanese firms in the United States might very well be both listening posts and generating stations at the same time. Why, in order to be such a listening post, would the activity have to be actually located in the United States? After all, journal articles can be read in Japan, and Japanese-based research personnel can attend professional meetings in the United States. The principal reason is that a U.S. location is likely to enable more effective "networking" within the U.S. R&D community than a comparable facility located in Japan. For instance, it is probably easier to hire topflight U.S. citizens to work at a U.S. facility under the control of a Japanese corporation than to work at a similar facility in Japan.

[2] This possibility was pointed out to me by Dr. Christopher T. Hill, Director of the National Academy of Engineering Manufacturing Forum, and I am grateful to him for sharing his insights with me.

Is the possibility of such listening post activity problematic from a U.S. interests perspective? This issue is taken up in the next section.

JAPANESE-CONTROLLED RESEARCH AND DEVELOPMENT IN THE UNITED STATES AND U.S. INTERESTS

To evaluate where U.S. interests lie with respect to Japanese control of R&D activities in the United States, one ideally would calculate the costs and benefits associated with these, including all costs associated with such intangibles as "loss of control of technology," including the loss that might occur through basic R&D listening posts as described immediately above. This, alas, would be a nearly impossible task, and all that is attempted here is a qualitative evaluation of what the costs and benefits are likely to be without any effort to quantify these.

The benefits of any R&D activity accrue to four sets of parties; the first three are producers (i.e., the firm that conducts the activity, or, more accurately, ultimately the owners of the firm); consumers (i.e., users of the products of the firm); and the public at large (where the "public" is not any of the above). Those benefits that accrue to the public at large are often called "external benefits" or "externalities." The fourth set of parties that can also capture some of the benefits are suppliers of inputs to the firm conducting the R&D. These suppliers include the firm's employees, whose marginal productivities (and hence wages) might be positively affected by product and process innovations resulting from R&D. They also include suppliers of purchased inputs to the firm, to whom technologies might be transferred in order that these technologies be embodied in the inputs.

For example, the Japanese automotive firms have shown some willingness to work with U.S.-controlled suppliers of auto parts so as to increase the quality of these parts, and this entails technology transfer. If these same suppliers then use this technology to improve quality of parts delivered to other manufacturers, the benefit of this technology transfer will accrue not just to the supplier itself, but to other auto firms and ultimately to the users of the autos.

However, it is also alleged that Japanese firms supply their latest and best technologies to customers and suppliers that are members of the same *keiretsu* family of firms prior to supplying these to non-*keiretsu* firms.[3] This could be problematic if the supplying firm holds a dominant market position and is able to use its technology to monopolize the market. But to the extent that such problems occur, they must be evaluated with care. A

[3] See, for example, U.S. General Accounting Office, "International Trade: U.S. Business Access to Certain Foreign State-of-the-Art Technology" (Washington, D.C.: U.S. Government Printing Office, September 1991), GAO/NSIAD-91-278.

certain amount of monopoly power on the part of an innovator of a new technology is seen by most persons expert in the economics of technological innovation as a necessary evil in a technologically dynamic industry (indeed, patents in principle grant a temporary monopoly to an innovator). What has been termed the "*keiretsu* problem" may in fact be little more than the way Japanese firms institutionalize this power. (Otherwise put, the same degree of monopoly power held by non-Japanese innovators, but manifested via different institutional arrangements, may be seen as quite tolerable; nobody complains too loudly if IBM develops internally a new microchip and supplies it only to other IBM operations.) But neoclassical economists generally contend that monopoly power is bad per se; this power is to be tolerated as a necessary precondition for innovation (or for economy of scale, or other sources of economic benefits), but only to the degree that is necessary for innovation to proceed (or for the other benefits to accrue). There is a level of monopoly power that is not acceptable and that cannot be justified on grounds of technological dynamism or any other economic basis. We shall return to this set of issues in the final pages of this paper.

Issues of market dominance aside, too much current discussion of the costs and benefits of foreign control of domestic R&D activity is predicated implicitly on the assumption that all benefits accrue to the producer or to the ultimate owner of the producer. This simply is not true. Some benefits from domestic R&D activities undertaken by a firm that is foreign owned will be captured by users of the firm's products, the public at large, suppliers to the firm, and even, as the example above shows, possibly the firm's competitors. Most of these persons will be Americans.

All else being equal, however, U.S. interests would be better served if any given R&D activity were under domestic U.S. ownership rather than Japanese (or any other foreign) ownership. The reasons are straightforward: those benefits from the activity that are captured by the firm would ultimately accrue to domestic owners rather than foreign ones.

That having been said, it must also be said that "all else being equal" does not hold. In the extreme, domestic ownership of an R&D activity might not be an option.[4] In such cases, a discussion of the pros and cons of

[4] Thus, for example, in her study *Foreign Investment in the United States: Unincumbered Access* (Washington, DC: Economic Strategy Institute, 1991), Linda Spencer decries takeover of U.S. high technology firms by Japanese and other foreign investors and implies that the (U.S. government) Committee on Foreign Investment in the United States (CFIUS) has been derelict in not recommending that the President block many more of these takeovers under the Exon-Florio amendment to the Defense Production Act. The implicit assumption —never really stated, let alone justified—is that in the absence of the takeover the high technology activity would have prospered under domestic ownership. Yet in those cases that CFIUS has investigated, a principal finding has often been that without foreign investment, the activity faced bankruptcy or shutdown, and for those activities a U.S. buyer could not be found. According to persons close to the CFIUS process, this finding has often been instrumental in CFIUS deciding not to recommend that the transaction be blocked.

foreign ownership of the activity boils down to whether it is better that the activity exist in the United States under foreign ownership or not exist at all (or exist somewhere other than the United States). A less extreme case would be a small, high technology company that is a candidate to be acquired by a foreign firm. The foreign investor might have the resources and will to develop the company's technology to a point where it is socially useful, whereas without the foreign investor the company would suffer a significant risk of faltering before the technology is fully developed. There are reasons why this can occur that go beyond an appeal to market failure (in this case, market failure would occur if the company failed to develop a socially useful technology that would earn its backers an adequate return because it could not raise the resources necessary to do so): the technology held by the company might, for example, complement technology held by the foreign investor in such a way that the value of the two technologies combined was greater than the sum of the values of the two technologies when kept separate.[5]

Thus, one issue that must be resolved when discussing whether foreign ownership of a domestic research and development activity is in U.S. interests is whether or not that activity is "additive." That is, it must be determined whether or not the activity represents an addition to the U.S. R&D base or simply transfer of ownership and control from domestic ownership to foreign ownership.

If the R&D activity is additive, it is much more likely to be beneficial to overall U.S. interests than if it is not. Even if foreign owners capture some of the benefits from the activity, other benefits will remain in the U.S. economy, such as is suggested above, those captured by users, suppliers (if these are domestically owned), and the public at large. Presumably these will exceed the costs to the economy of the activity. It must be noted here however that this last need not necessarily hold: the activity will use inputs such as U.S. R&D talent and might bid up the price of inputs, to the detriment of other activities. In principle, the opportunity costs associated with these inputs could exceed the benefits accruing to the United States. But in practice this seems (to this author at least) to be very unlikely. As noted in the previous section, the percentage of U.S. R&D activity that is under foreign control is quite small, and it seems unlikely that this activity would greatly affect input prices.

Even if the activity is not additive, it is not invariably to the detriment of the United States for it to be under foreign ownership. An issue here is

[5] These considerations are quite close to those developed in much greater depth by John Cantwell; see in particular "The Technological Competence Theory of International Production and Its Implications," *University of Reading Department of Economics Discussion Papers in International Investment and Business Studies*, series B, vol. III, no. 149 (Reading, U.K.: The University of Reading), as well as the paper by Cantwell in this volume.

whether or not the activity is likely to generate more benefits as part of the foreign parent firm's organization than if it is not. As suggested earlier, it is possible that the competence (and value in terms of potential to generate benefits) of a U.S. R&D activity that comes under foreign control is enhanced by this control: complementarities might exist between the new owner and the activity that enhance the value of both.

But against this of course must be weighed any benefits captured by the foreign owner that otherwise would be captured by Americans. These would include any "first-mover" advantages that might accrue from control of the relevant technologies (to the extent that these are captured by the owner or by close affiliates of the owner, e.g., other members of a *keiretsu*; here it must be remembered that benefits resulting from first-mover advantages might accrue to customers or suppliers as well as to the innovating firm itself). Foreign ownership does imply that some benefits will be captured by foreigners, and if the activity is not additive, these may be ones that otherwise would be captured by Americans.

On the balance then, where will the U.S. interests lie? The standard presumption regarding R&D is that this type of activity generates significant externalities, and these almost by definition will be captured by Americans if the activity is located on American soil irrespective of the ownership. Some of these have the character of a public good and may be captured by persons other than Americans but this would happen irrespective of ownership. What are known in the recent literature on clustering of economic activities as thick market externalities will almost surely be enhanced by R&D activities under foreign ownership but located on U.S. soil, and benefits will result that are captured by Americans. A full description of "thick market externalities" is beyond the scope of this paper, but these can be described in a nutshell as the propensity of R&D activities to be located in close proximity to other activities, because the combination of activities in close proximity to one another generates a pool of resources that can be tapped by all activities.[6]

The listening post function of basic R&D activity described at the end of the previous section of this paper really amounts to participation in these thick market externalities. Is such participation by Japanese-controlled entities desirable? The answer depends in large part upon whether or not as a result these entities bring something to the party as well as take something away. To some extent, this rests upon whether or not these activities generate any new knowledge that can be tapped by American participants in the network (and so, again, the issue is whether or not the Japanese-controlled activities are additive). But it also depends upon whether the U.S.-based

[6] For more on this, see Paul R. Krugman, *Geography and Trade* (Cambridge, Massachusetts: The MIT Press, 1989).

activity is able to tap into the R&D activities in Japan of the Japanese parent firm, and to bring knowledge from these into the U.S. network. I know of no study attempting to determine whether or not either of these actually occurs, and indeed the answer might be "it is too early to tell."

Also relevant to this issue of whether basic R&D listening post activity is consistent with U.S. interests is an issue of reciprocity: are U.S.-owned firms able to "plug" themselves into Japanese networks inside of Japan? Recent research on this matter suggests that in fact numerous U.S. firms have been able to do so.[7] To the extent that this is so, and given that diffusion of technology is generally held ultimately to be to the advantage of society at large, even if it were to be determined that Japanese R&D listening posts bring little knowledge into U.S. R&D networks relative to the information they derive from these networks, it might be foolish to attempt to shut these activities down if to do so risked reciprocal action on the part of the Japanese government. Two-way transfer of technology is almost surely a positive-sum game. There almost surely would be net costs both to the United States and to Japan of closing off this transfer, and reciprocal access to each other's thick market externalities is almost surely jointly beneficial even if the case could be made that one party would benefit at the expense of the other if one nation were to be unilaterally open to listening posts of the other while the second were to be closed in this regard.

On the whole, I would think that the case is strong that net benefits are generated by foreign-owned R&D activities located in the United States even without appeal to reciprocity. The case is enhanced if the foreign owner possesses complementary technologies (or, perhaps more pertinent, technological capabilities) that enhance the value of the output of the activity, and the case is rather strong that Japanese firms that acquire or establish U.S. R&D facilities likely will possess such complementary assets. It is especially enhanced if indeed Japanese firms enlarge basic research in the United States to the extent that the U.S. activities are able to generate (as well as capture) basic knowledge. The externalities associated with basic research are generally believed to be significantly higher per unit of input than for applied R&D.

The case in favor of foreign-owned R&D activity is also enhanced if the firms undertaking the R&D source components or other inputs from domestically-owned suppliers, given that these suppliers are capturing some of the benefits from the R&D. But the case is somewhat weakened if

[7] See, for example, Global Competitiveness Corporation and Technology International, Inc., "Survey of Direct U.S. Private Capital Investment in Research and Development Facilities in Japan," Final Report to the Science and Engineering Indicators Program, National Science Foundation, January 28, 1991.

Japanese-controlled firms only establish backwards linkages with firms that are members of a *keiretsu*. However, backward linkages with domestically-owned suppliers should not be regarded as a necessary criterion for there to be net benefits to the United States from foreign-owned R&D activity.

As already noted, the main issue centering on *keiretsu* is that linkages among *keiretsu* members could result in undesirable levels of dominance by a *keiretsu*. There doubtlessly will be continuing discussions, with friction, at the official level between the United States and Japan regarding competition policy and the apparent willingness of the Japanese government to tolerate higher levels of industry concentration than are seen as desirable in the United States. But with respect to affiliates of Japanese *keiretsu* member firms operating directly in the United States market, there are unilateral actions that U.S. antitrust authorities could take to remedy anticompetitive practices. Thus, although these practices might very well be objectionable, the problems in many instance could be remedied via application of U.S. antitrust laws.

Even so, there will be cases where foreign ownership of a particular R&D activity or high technology will not be in U.S. national interests. Some of these will fall under the rubric of national security.[8] But while legitimate national security exceptions exist, it is easy to envisage "national security" becoming a rationalization for xenophobic policies that serve no national interest, security or otherwise. Therefore, national security exceptions to an otherwise open policy towards foreign ownership of economic activity (including R&D activity) should be truly exceptional. While there are legitimate national security exceptions, the danger of allowing national security to be abused is almost surely far greater than the dangers to security of foreign ownership of firms operating in the United States. Where foreign ownership is disallowed in a specific case, the reasons for disallowing this ownership should be clear, specific, and compelling.

[8] See the discussion in Chapter 5 of Edward M. Graham and Paul R. Krugman, *Foreign Direct Investment in the United States*, 2nd Edition (Washington, D.C.: The Institute for International Economics, 1991) and sources cited therein.

IV

POLICY IMPLICATIONS

Policy Implications of Japan's Growing Technological Capabilities: Framing the Issues

RICHARD R. NELSON

My aim here is to provide a frame for discussion of the policy issues associated with the rise of Japan as a major technological power. I do so by flagging five matters. First, there has been significant convergence of the technological capabilities of the major industrialized nations, and this was inevitable and will not be reversed. Second, since the early 1970s the U.S. economy has seen very slow growth of productivity and incomes, compared with growth rates during the earlier postwar era; this phenomenon often is associated with and indeed blamed on convergence, but likely has little to do with it. Third, while in the early postwar era the United States had special advantages in what have come to be called "strategic" industries, in recent years this has been less and less the case; however, whether this significantly disadvantages the United States is an open question. Fourth, the national institutions and policies supporting the development of technology are complex and varied, involving much more than simply "private enterprise" and "markets," and this is true in the United States as well as Japan; the question of what is appropriate and fair government involvement in technological advance and what is not does not have an easy answer. Fifth, the relationship between national policies and national technological capabilities has become even more complex in recent years as a result of the increasing internationalization of business. I want to briefly develop each of these themes.

CONVERGENCE

During the quarter century after World War II the United States led the other countries of the world in productivity, income levels, and command of technologies across a very wide front. I believe it is useful to distinguish two components to the U.S. technological lead. One component was in mass production industries like automobiles, steel, and meat packing, and this was of long standing. It reflected the fact that, as long ago as the close of the nineteeth century, the United States was the world's largest, richest common market, and international trade in manufactured goods was limited. The other component, the commanding U.S. lead in "high tech" industries, was new. Before World War II the United States was scarcely a slouch in high tech, but Europeans felt no sense of inferiority here. What led to the American lead here was the massive investment in education in science and engineering, and in research and development, that the Americans made after World War II. The investments made by other industrial nations were much, much lower.

Over the last five years or so there has grown up a significant economic literature on "convergence." For the most part, that literature treats the American postwar lead as something of a "sport," having to do largely with the fact that our major industrial rivals had been badly hurt by World War II, and therefore as something that naturally would dissolve as they recovered. My argument above is that the U.S. lead was not a sport and had something but not very much to do with the wartime devastation of our industrial rivals. And there was nothing "automatic" about the convergence process that did occur after they recovered.

There were two major factors behind convergence. First, largely as a result of U.S.-pressed policies, the world increasingly became a common market in manufactured goods. With easy access to foreign markets, the size of one's home market mattered much less. And so the United States lost its long-standing advantages in mass production industries. The second major factor was that other advanced industrial nations came to match the large investments in science and engineering education, and in research and development, that the United States had been making. In the early stages of this catch-up, firms in foreign countries became more sophisticated and more rapid imitators of technologies first introduced in the United States. But by the late 1970s in many areas foreign firms were close to where U.S. firms were.

These two developments interacted strongly. Internationalization of trade and business, combined with the catching up of other countries to U.S. levels in science and engineering education, and in research and development, to make technologies international rather than national.

How is all this germane to the topic at hand? It is germane because much of the rise of Japan as a technological as well as an economic power reflects exactly the processes of convergence I have discussed above. Japan did it through massive investments in education, and in research and development. But she couldn't have done it without the internationalization of trade.

The other side of this coin is that, in my view at least, one will not see in the foreseeable future the opening up of big gaps in technological capabilities, among the major industrial nations of the sort that one saw after World War II. It is extremely unlikely that the United States possibly could redeem those kinds of leads. On the other hand, I doubt seriously that Japan will be able to establish and hold them. The major industrial nations of the world are tied together economically and technologically as never before.

SLOW GROWTH IN THE UNITED STATES

In my view, convergence would have occurred rapidly over the last quarter century whether economic growth in the United States had been fast or slow. However, the rate of productivity and income growth in the American economy slowed down significantly in the early 1970s from what it had been earlier. Perhaps that has hastened convergence. But its more important effect has been to thwart the expectations of Americans regarding what their economic future holds. Convergence has been associated with "bad times" here, as contrasted with good times. Economists have gone over a long list of explanations for the productivity and income growth slowdown. During the middle 1970s, it was energy price shocks. During the middle and late 1980s, low savings rates have become the culprit fingered by many. Problems with American education constitute another popular culprit. However, I think that it is fair to say that economists simply don't understand very well the reason for the growth slowdown.

I doubt seriously that the rising technological and economic competencies of other nations would have bothered Americans so much had these not been accompanied by the slowdown in the United States of productivity and income growth. More, there clearly is a tendency of some to see stagnation in the United States as a consequence of rising competencies abroad, particularly as these have been manifest in a surge of U.S. imports and a decline of U.S. industries in fields where, during the heyday of the 1960s, we used to dominate.

However, in my view at least, it is highly unlikely that the rising strengths of other nations, particularly Japan, have been an important factor behind the weak performance of the United States. Strong performance abroad and the consequent sharp increase in imports in many fields certainly have been a cause of the erosion of employment and output in a number of industries that used to pay high wages and to be relatively profitable. A good case can be made that the result has been a transfer of real income among Americans between those who used to be fortunate enough to be employed by those industries, and the rest of us who now are getting better products at lower prices. But this is not an argument that if foreign economies had not advanced so rapidly, or if the United States had insulated itself from their growing prowess by blockading imports, the real productivity and income of Americans would have grown faster. Indeed, I think this highly unlikely.

There is a somewhat different argument that I find more plausible. It is that the increasing openness of the United States to imports, and the internationalization of financial markets, diminished the ability of the United States to operate its economy with demand pressing hard on capacity and with low levels of unemployed, and that this has fed back to diminish our growth rate. But this is not a story linked particularly to the growing technological sophistication of Japan.

THE "STRATEGIC" INDUSTRY CONCEPT

There are two somewhat different concepts of a "strategic" industry that have some currency within economics. One is a relatively new one, associated with the rise of what has been called the "new" trade theory. It is based on the argument that, in industries that are inherently oligopolistic, because of large economies of scale in production, or large up-front R&D costs, or strong learning curve effects, the countries where these industries reside may be advantaged economically because their equilibrium profits and wages are higher than in the run-of-the-mill more structurally competitive industries. A different argument is that a nation may be advantaged if it possesses industries that generate a considerable amount of "externalities" and that these externalities tend to remain within national borders. This latter argument sometimes is seen as connecting with an older one, associated with Schumpeter, to the effect that at any time there tend to be a small group of industries that are strategic in the sense that the technological advances they create have very widespread impact, being the basis for technological advance across a wide spectrum of other industries. In recent years, microelectronics and new materials have been argued to have this characteristic.

It has been argued that, while the United States used to have these industries, it is precisely these strategic industries that we now are losing to Japan. More, the reason Japan is gaining ascendancy in these industries has a lot to do with the policies of the Japanese government specifically aimed to help these industries. According to this argument, if the United States does not match these policies, or otherwise protect these industries, the result will be highly detrimental to the American economy. This argument clearly lies behind the beliefs of many who posit that the Japanese technological and economic successes of the 1970s and 1980s are the cause of the poor performance of the American economy over this period. Current arguments to this effect lie behind the political thrust toward protection and toward more active U.S. policy in support of "strategic" industries.

I do not want to argue against the point that, in certain circumstances, industries where firms have considerable market power are able to pay higher wages and reap higher profits than more competitive ones, or against the argument that technological advance in certain industries yields widespread externalities. However, I proposed earlier that the erosion of market power in the American steel and automobile industries, because of import competition, probably is better regarded as having caused a redistribution of real income among Americans than having caused a transfer of real income from Americans to Japanese and other foreigners. International competition in these "natural oligopolies" is fierce, and it is not at all clear that the surviving companies in these industries are all that profitable. Also, while I believe strongly that technological advance in microelectronics, and in materials, yields widespread benefits, they are not captured by the companies introducing the new products; it is not at all clear to me that these benefits are largely captured by firms, and citizens, who reside within the country housing the innovating firms. What is striking about these industries is the web of transnational intercorporate technology trading arrangements that have developed over recent years. I come back to a point I made at the outset. National borders seem to mean far less economically, and technologically, than they used to.

THE INDUSTRIAL POLICY DISPUTE

Americans over the years have put in place a large variety of policies aimed at enhancing the technological capabilities of "our" firms. For example, we long have had significant funding of agricultural research. Our publicly funded biomedical research program is by far the world's largest. U.S. government agencies routinely target research monies at technologies of interest to them. SEMATECH is one of the largest public programs supporting research in semiconductor technology. Nonetheless, many of us have the perception that we do very little of that; that foreign governments, particularly Japan, do much more; and that this is "unfair." It is not quite clear what the basis of that claim is —what divides "fair" from "unfair" policies. Sometimes fair seems to mean what we do, or claim we do, but this position clearly is not acceptable internationally, even if we could agree on what we actually do.

A better position might be Kantian, with unfair policies being those that, if everyone engaged in them, would make everyone worse off, but if some do and some don't the former are advantaged and the latter disadvantaged. In the economists' jargon, government support or protection or coordination ought to be defendable on the basis of persuasive arguments about "market failure." If it can be argued that, while positive public action may give advantage to a particular national industry, such support can be argued to increase economic efficiency, the program is not on its face "unfair."

But the problem with this line of argument is that "market failure" is ubiquitous in the activities associated with industrial innovation, and thus subsidy or protection or guidance could be efficiency enhancing, and hence the game of active industrial policy need not be negative sum. What has come to be called "the new trade theory" recognizes some of this, nervously. If there are large "up-front" R&D costs, or significant learning through doing or using, or major externalities in certain activities like research and training, the simple arguments that free trade is "Pareto Optimal" (in the parlance of economists) falls apart.

Of course "market failure" is greater in certain activities than in others. Also, government competence and incentives are more likely to lead to productive programs in certain arenas than in others. Further, it is apparent that competitive protection and subsidy among nations can go beyond any level conceivably justified on grounds of "efficiency." It is in the interest of all nations to reign in such tendencies.

Nor is it likely that simple rules—for example, that government support of R&D on public sector needs and for "basic" research is efficient and fair, while direct support of industrial R&D aimed to develop products for a civilian market is both inefficient and unfair—will carry the discussion very far. This argument certainly can be used to attack European government subsidies to Airbus. But Europeans rejoin that government help was needed to overcome the huge head start American companies had won in large part as a spillover from military R&D, and can be justified economically both on infant industry grounds and as a policy to avoid the development of a one-company world monopoly. And what of government support for telecommunications R&D where telecommunications is a government service? Americans are prone to argue that telecommunications should be privatized, but there surely is limited agreement on that. And what to one eye is blockage to competition in public procurement, to another is a valuable close relationship between customer and supplier.

Nor are there clean lines separating "basic research" from applied. No one seems to object to government support for research on the causes of cancer (although a breakthrough here may give the firms with close contact with the research a major advantage in coming up with a proprietary product). But what about research to advance agricultural productivity? To improve crops growing in a particular national climate? Research on super-conductivity, or on surface phenomena in semiconductors, conducted in universities? Conducted in an industry cooperative research organization? In a particular firm?

Presently, different countries are trying various of these approaches to enhancing technological competencies. In my view, we should welcome the diversity, not label it "unfair," because we have a lot to learn about what kinds of policies are effective and what kinds are not.

INTERNATIONALIZATION OF BUSINESS AND TECHNOLOGY

I want to conclude by returning to my opening point. A central irreversible development of the past quarter century has been the internationalization of trade, business, and technology. An important consequence is that national policies aimed at enhancing the technical capabilities of "national" firms increasingly are at odds with the structure of business. National firms, particularly in "strategic industries," now often have a set of technological agreements and relationships with "foreign" firms. In the United States and Europe (less so in Japan) many of the establishments within national borders have their central headquarters in other nations. As Robert Reich has asked, "who is us?"

However, I would like to put the matter another way. While this conference is focused on the consequences for the United States of Japan's growing technological capabilities, perhaps that question is too narrow and slanted to orient the discussion in a useful way. Let me propose that the real question is how the United States can learn to cope better with a world where technology is international, where the advanced industrial nations are basically on a par with each other in terms of access to technology, as are the firms that happen to be headquartered in different nations. We must understand that, today, national borders and citizenship, including our own, mean much less economically than they used to mean.

Policy Implications for the United States: Comments

HIROSHI OTA

Japan's growing technological capability represents both a challenge to, and an opportunity for the United States. First it is widely viewed as a challenge to the United States. In recent years, U.S. technological leadership, which in the 1950s and 1960s was undisputed, has gradually eroded. Industries such as consumer electronics, steel, automobiles, machine tools and semiconductors have one by one lost their competitive strength, and the main challenger has been Japan. In addition, there is concern in the United States that in coming years, the competitive edge that America enjoys now in such industries as computers, aerospace and biotechnology may also erode.

It seems evident, however, that the significance of the Japanese technological challenge is not so much with regard to specific industries as to industrial competitiveness in general. It is related to the question of technology policy at the governmental level and to the question of the management of technology at the corporate level.

At the government level, the Japanese challenge seems to have raised a series of questions related to technology policy such as: (1) What should the role of the government be in the development of technology? (2) What kinds of initiatives should the government take in promoting research consortia? (3) What kinds of fiscal, monetary, legal and regulatory policies should the government have in order to lessen or eliminate obstacles and create favorable conditions for the private sector to strengthen industrial competitiveness?

During the past decade, a considerable amount of debate has taken place concerning the competitiveness of U.S. industry and how to strengthen the U.S. technological base. A conspicuous increase in recent years in the discussions about U.S. technology policy seems to be, to a great extent, a response to Japan's technological and industrial challenge to the United States.

For a Japanese observer, it is striking that after such serious discussions for almost a decade, often carried out with a deep sense of crisis, there still does not seem to be a consensus on the need for an appropriate technology policy. This may well be because an adoption and implementation of a technology policy could be considered a path towards the adoption and implementation of an industrial policy, which seems to be conceptually rejected by many in the United States. To a Japanese observer, the most important response by the United States to the challenge of Japan's growing technological capability seems to be forging a consensus on the need for a technology policy.

Although it is difficult to assign priority to various elements of U.S. technology policy, from a Japanese point of view a need to remedy the inclination of American corporations to have short time horizons seems to be one of the most crucial elements.

It is widely pointed out that the short-term inclination of U.S. corporations is a major constraint to conducting patient research and development activities and investing in plant and equipment on a long-term basis, both of which are crucial in introducing competitive products into the market. A number of the factors contributing to the short-term thinking of U.S. corporations have been pointed out. Among them, the character of the U.S. stock market seems to play an important role. One possible measure for the U.S. government to take, as suggested by an American friend of mine, is to introduce tax measures to discourage quick turnovers of shares by institutional investors and to reward those who hold shares over a longer period of time.

In formulating and implementing a technology policy, one cannot possibly ignore the recent phenomenon of rapid growth in international technological and economic interdependence. Government-level cooperation in various aspects of science and technology and the activities of multinational corporations have contributed to the emergence of a transnational technology base. "As a result, it is becoming increasingly difficult to distinguish one firm's technology from another's or one nation's technology base from another's."[1]

In such an environment, it is desirable and perhaps even necessary to try to avoid including "technonationalistic" elements in technology policy. Such elements would surely restrain the capability of private corporations

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[1] Thomas H. Lee and Proctor P. Reid, eds., *National Interests in an Age of Global Technology* (Washington, D.C.: National Academy Press, 1991), p.72.

to take advantage of the emerging transnational technology base. From this point of view, a move to interpret the meaning of "national security" of the Exon-Florio amendment more broadly to include the concept of "economic security" causes concern on the part of many. If, for example, foreign direct investment in the United States were to be screened by the Committee on Foreign Investment in the United States from a broadly defined economic security point of view as well as from the standpoint of national security more narrowly defined, it could run counter to trends in the world economy, and might well limit the possibilities of contributions of foreign corporations to U.S. economic growth and technological and industrial strength.

Another visible element in U.S. technology policy that might be characterized as technonationalistic is the limitation of U.S. government-funded research grants or access to the fruits of U.S. government-funded research to U.S.-owned companies. Exclusion of foreign participation in SEMATECH is a conspicuous example. Such an approach does not seem to reflect the reality of increasing global alliances being formed by U.S. corporations and may well limit the potential of such research to contribute to the increase in technological capabilities in the United States.

With regard to the U.S. private sector, which is of course the main actor in the technology and competitiveness theater, the challenge of Japan's growing technological capability is related to the ability to apply technologies efficiently to manufacture competitive and high-quality products. The Japanese production system raises many issues for U.S. corporate managers, including the increasing importance of needs-oriented, as opposed to more basic research and development; the value of lean and flexible manufacturing systems versus the traditional mass production system; the significance of designing for manufacturability and quality; the advantage of teamwork in the product development process; the vital importance of a focus on the manufacturing process and continuous improvement; the need to train skilled workers and engineers; and the serious negative impact of short time horizons. [2] Now U.S. corporate managers seem to be faced with questions about the suitability of various aspects of U.S. corporate practice to the requirements for competitive production based on high technologies. The need to respond to the Japanese challenge does not mean that U.S. corporate managers have to emulate Japanese management in its entirety, but it seems that at least some aspects of U.S. corporate practice have to change.

As a matter of fact, some elements of Japanese practice have already been adopted by American industries. One such example is the introduction of production *keiretsu* in the form of the stable supply of parts in the U.S.

[2] Michael L. Dertouzos, Richard K. Lester, and Robert M. Solow, *Made in America* (Cambridge: The MIT Press, 1989).

automobile industry. Here perhaps Japan should not claim that U.S. corporations started adopting Japanese corporate culture. It is more likely that U.S. corporations are simply following the path Japanese corporations happened to tread first.

In addition to these challenges, Japan's growing technological capability presents opportunities to the United States. It is a very important part of the convergence in technical capabilities of industrialized nations, a trend that has accelerated since the mid-1970s. This trend has been accompanied by another feature that has become increasingly visible during the past two decades, which is a surge in international foreign direct investment and a proliferation of transnational corporate networks.

In the context of U.S.-Japan relations, there has been rapid growth in Japanese direct investment in the U.S. manufacturing sector since the mid-1980s. There has also been a rapid increase in Japan-U.S. corporate linkages in such high technology industries as aerospace, computers and peripherals, semiconductors and semiconductor manufacturing equipment. Investment in Japanese R&D facilities by U.S. corporations has increased, and now more than 70 U.S. organizations operate R&D facilities in Japan.[3]

These developments mean that there is a growing tendency for U.S. and Japanese technologies to get mingled and that the technological base for U.S. corporations is broadening, which has important implications for U.S. technological competitiveness.

In order for the United States to seize these opportunities effectively, it seems important for the United States to overcome a traditional psychological attitude toward foreign technology, namely, the "not-invented-here" syndrome or "parochialism" with regard to technology and industry. There seems to be a growing realization in the United States that today technological capabilities are globally distributed and that the diffusion of technological advance across national borders is rapidly expanding. The fact that the U.S. government insisted on "comparable access" in the negotiations to amend the U.S.-Japan Agreement on Cooperation in Research and Development in Science and Technology reflects such a recognition. The United States may well try harder to have access to and to utilize Japanese technology. This implies that on the psychological level, it might be necessary for Americans to adjust their views on and approaches to foreign technology to reflect the changing position of the United States from an undisputed technological leader of the world to the first among equals.

As for possible U.S. policies to take advantage of opportunities presented by Japan's increasing technological capability, I would like to make the following observations:

[3] National Science Foundation, *Survey of Direct U.S. Private Capital Investment in Research and Development Facilities in Japan* (Washington, D.C.: 1991).

1. Measures may be taken to further encourage the flow of technology from Japan to the United States. They include efforts to gather and disseminate information on Japanese technology, which are already under way in various forms. The Japan Technology Program of the Department of Commerce is doing valuable work in this respect. The U.S. government could perhaps step up efforts to secure "comparable access to major government-sponsored or government-supported programs".[4] Recent U.S. interest in the Intelligent Manufacturing System and New Information Processing Technology projects is a welcome development.
2. Corporate alliances and joint ventures between U.S. and Japanese corporations could and should be further encouraged. Such alliances, needless to say, are primarily a matter for private corporations to decide. But the U.S. government could encourage such moves through measures that might include the relaxation of the application of antitrust regulations and allowing Japanese corporations to participate in U.S. research consortia.
3. It is desirable for the U.S. government to continue to ask the Japanese government to play its role in enhancing collaboration in technological and industrial fields. Although much has to be done by the United States to seize opportunities presented by Japan's growing technological capability, Japan can also be called upon to behave in such a way as to turn technological development into a positive-sum game. The Japanese government should establish it as a rule that government-sponsored research projects will be opened internationally, and hopefully the U.S. government would respond by doing likewise. Japan should step up efforts to redress the still existing imbalance in the flow of researchers between the two countries by expanding fellowship programs and by upgrading the research facilities of Japanese universities and national research laboratories. Japan should also improve its business environment so that obstacles for U.S. corporations to increase substantially direct investment in Japan are removed.

Japanese corporations should make greater efforts to transfer their technology more smoothly. It is also necessary to increase transparency concerning their strategies, especially with regard to direct investment in the United States. Japanese corporations should ensure that their investments are not merely or primarily intended to extract technology from the United States.

For the United States to ask Japan to play its role will not be putting *gaiatsu* (external pressure) on Japan, because it is in Japan's own interests to harmoniously share the fruits of technological development. Japan can prosper towards and into the twenty-first century only if the U.S. technological base is maintained and strengthened, and if U.S. industries remain competitive.

[4] Agreement between the government of Japan and the government of the United States on Cooperation in Research and Development in Science and Technology.

Comments on Policy Implications

ERICH BLOCH

INTRODUCTION

By the last session of a two-day symposium, and the last speaker, which I am, the audience may conclude that everything worthwhile has already been discussed. By this time one has also seen that different viewpoints can lead to radically different conclusions. I am not going to resolve these diverse opinions and conclusions, but maybe I can add to their understanding.

One point everyone can agree on: Japan's increasing technical capabilities are real, and their importance is not only affecting Japan's economic and political standing, but the relevant standing of all other nations as well—including our own.

THE U.S. ECONOMY

Over the last decade we have seen vast changes in the composition of our industry and our export trade. We have seen the demise of many growth sectors, such as electronic consumer products, photographic equipment, robotics, instrumentation and machine tools, optical glasses and ceramics. Many of these sectors were lost because of increased competition, or better products from other sources of supply; others were lost because the primary sector they were supplying was no longer centered in this country. The United States has lost other sectors because the needed capital investment was not available; still others are gone because of the shortsightedness of management.

In other fields like semiconductors, the United States has lost significant market share, just as she has in computers. This loss of market share, and loss of industry sectors, is reflected in a negative trade balance. This negative trade balance has persisted even though the value of the dollar fluctuated from high to low. Not even increasing exports of paper, wood, agricultural products, or scrap iron can offset our failure to maintain world market share in high-value products and growth sectors.

Content in trade does matter. Technology standing does matter. In fact, trade and our technology leadership—or lack of it—are leading indicators of what is in store for us. It does not take much intelligence to predict that the future competitiveness of the United States is seriously jeopardized if we do not fundamentally change our ad hoc technology policy.

WHY THIS CHANGE FROM THE 1950S?

These changes cannot be explained in their totality by simply stating that other nations are catching up with U.S. leadership, as some people assert. Neither can this change in status be explained by observing a shift in the technology paradigm, although both of these changes have an influence on the position of the country relative to its trading partners.

There are more fundamental forces at work. There is a certain amount of complacency in the business community, which has been hanging on to the past for too long. The Taylor approach to mass production is superseded today by new techniques that stress flexibility and variability. This change is supported by new tools and devices like robots, computers and programmable manufacturing cells. Economy of scope, rather than scale, is the organizing principle in this global economy, with information technology and knowledge-based industries playing an increasingly important role.

But other reasons contribute equally. For most of the postwar period, we created a vast array of new industrial sectors. Good times, and a growing economy, created waste and bureaucracy simultaneously, which left us with overbloated organizational structures that had too many levels, in a tall and narrow organizational pyramid.

Business decisions came to be based on criteria that were more curtailing and narrow in scope. The time horizons of business decisions narrowed considerably. Tomorrow's short-term profit-and-loss statements became more important and sacrosanct than the decisions required to ensure the long-term survival of the enterprise. Financial manipulations too often took priority over technical or product strategies.

These attitudes and shortsightedness can be laid at the door of industry and its managers. However, the federal government is not blame free.

The comfortable and self-righteous position of the last and present administration to "let the market decide" can only work if one's major trading partners live by the same rules and philosophy. This, however, has not been the case. The coordination, guidance and national strategies of other governments that are used to help their own industries collaborate among various sectors of society constitute a formidable handicap for the United States to overcome, because we are structurally and philosophically unwilling to accommodate ourselves to even a modicum of priority setting and cooperation between our public and private sectors.

This separation of the private and public sectors is a severe handicap at a time of rapid change. Technologies are advancing at an increasing speed; the time to market is shorter; competition is increasing, while the cost of research, technology development and manufacturing capital is increasing equally fast. The pace of progress, and the need for a modern infrastructure are such that individual companies cannot possibly muster the investment needed to stay competitive, without the nation investing in a modern technical infrastructure that is world class. This long-term goal must be simultaneous and cooperative.

Above all, confusing technology policy with industrial policy does not help stem the erosion of our leadership.

In addition to the adverse effects of outmoded management strategies and policies, the United States is also handicapped by the high burden the Cold War has imposed on us. It inhibited and curtailed investments in education, technology, and technical infrastructure, which are now so urgently needed.

The "spin-off", or crossover, from our investment in military research and development, into the civilian sector, is significantly decreasing as the drivers and precursors of technology increasingly come from consumer products—a development that will only accelerate in the future.

The change from the national self-contained market to a global one was an event that profoundly changed the way we should be doing business, and the forces that are acting on our companies and our industry.

WHAT TO DO?

We need to recognize forthrightly our deteriorating ability to compete successfully in an expanding and ever-changing world market. We can not afford to ignore it or explain it away with views that are comfortable, but not true, such as the inevitability of others catching up. We have long passed the catch-up phase.

Along with realism, we need leadership—leadership at the highest level. We have a science policy. But our so-called technology policy is a series of unconnected events at best. A technology policy would give the United States a vehicle to right many of our current wrongs, such as the imbalances in the federal budget between defense and civilian research and development, between technology and science, and between university and government laboratories. Such a policy could also address the urgent needs of educating and retraining our work force.

An aggressive technology policy would deal with priorities. In research and development, the needs and opportunities are always greater than the resources that are available. We must choose. This means sharing the cost with others, and cooperating in return.

LEARNING FROM OTHERS

By putting a technology policy in place, it behooves us to define technology appropriately. It not only includes the hardware and software aspects of a process or product, but also the intangibles—the human factors—that make up our manufacturing and technology system, the social and management system that provides the environment in which an individual or group operates and works. This broader definition of technology, and engineering in particular, also needs to be reflected in our college education curriculum. Today that is not the case.

If we allow this expanded definition of what constitutes a technology policy, then it becomes clear that the management approach is as decisive as a breakthrough in hardware, or that the breakthroughs in the soft sides of technology, like inventory control concepts, are as determining to success as new inventions.

Add to this the emphasis on quality as one of the areas of focus and one realizes that Japan has been ahead of both the United States and Europe in considering the systems aspects of technology. Through this approach, Japan has gained inside advantages over the more compartmentalized formula practiced here in the United States.

We are too obsessed with Japan, as has been pointed out elsewhere in this discussion. We need to define and exploit our comparative advantages. We have a lot of them. This would be a more positive step than simply bemoaning the fact that our system does not allow or provide some of the flexibilities and advantages of the Japanese system.

WHAT ABOUT JAPAN?

Japan also has its share of problems, including an increasing disinterest on the part of its engineering and science students in manufacturing fields of employment. These critical manufacturing fields are still suffering from a bad image by being nicknamed "3 D"—dull, dangerous, and difficult.

Japan has also shown an abysmal neglect of its university research establishment, and in its lack of home-grown basic research. Japan is a country that is faced with an aging population and a declining college-age population. Its inappropriate trade policies have caused friction not just with the United States, but with Europe and other countries as well. Japan's domestic policies and infrastructures reflect a fortress mentality.

If some of these observations about Japan sound contradictory, it is because they reflect the contradictions that one encounters in Japanese society. As an example, statistically Japan is one of the richest countries in the world, but this wealth is not reflected in the individual living standards of its citizens. Just as Japan touts education—to the point of making it the focus of competition in early childhood—university research is still comparatively weak.

U.S.-JAPAN RELATIONS

I want to spend a couple more minutes on what we can do together—the United States and Japan—in this vital area of technology policy.

First, we must cooperate and compete, and do both simultaneously. This is not a contradiction, but two dimensions of our national relationship. The litmus test will be if the interactions we have contribute to building the domestic strength of both nations, or advance one to the detriment of the other. Because this test will depend as much on perception as on reality, we should not be surprised to find that friction and misunderstandings occur.

The frictions will be with us for some time to come, because they are not about one issue—such as symmetry in basic research—they have to do with a plethora of things, spanning technological questions, as well as political and even cultural ones.

There are institutions on both sides to serve as facilitators and conveners for discussions, as well as serving to provide an objective assessment of benefits that collaboration should yield. The Japan Society for the Promotion of Science and its committees here and in Japan, and the National Research Council's Committee on Japan are two quasi-private organizations that can serve this purpose.

Venues are not sufficient, however. We should agree on a number of objectives that address these issues. I would suggest

- more symmetry in basic research between the two countries;
- increased participation by U.S. university and industry researchers in Japanese government-sponsored programs;
- developing new international "rules of the road" to govern high technology competition.

The importance of technology and technological globalization means that we cannot be content with the traditional trade policy framework, but must consider issues that relate to fundamental, systemic differences. These include R&D subsidy policies, integration of information networks and global standards, intellectual property rights and other standards that affect global competition as much as trade questions do.

It will take some time to build these new rules. In the meantime, the U.S., European and Japanese governments can support some cooperative R&D ventures and develop joint efforts to address global problems, as has been proposed in the past. We need to remember, however, that there is a need for earlier and more in-depth consultations among countries on global program proposals, such as the Intelligent Manufacturing System, the Human Frontiers Program, the Superconducting Super Collider, and others to avoid misunderstandings.

A major obstacle to cooperation and understanding is a lack of symmetry in market access. Neither the U.S. nor the Japanese market is completely open, but the U.S. market is more so than the markets of Japan or of most European Community countries.

A key to the solution lays with multinational corporations and the key role they play in setting the context. To the extent that they transfer technology, assure value-added production, and train and employ locally, they will be welcomed by host countries. On the other hand, there can be problems if foreign investments lead primarily to the buying up of small innovative companies or plants, add little to the technological infrastructure of the country, and are not designed for the long term. Foreign investment will then be seen as problematic, and will not serve as a tool for international understanding and cooperation.

CONCLUSIONS

We must recognize that we are now in a new global environment, where knowledge itself is the driving force behind global competition.

For that reason, my focus has been on the increasing importance of technology to the fate of countries and nations, on the accelerated pace of technological development, as well as on the spread of technology across the globe. We must also recognize that there are tensions between the globalization of technology, and national interests in building economic and technological strength.

These are just a few of the issues that need to be addressed. As I said in the beginning, the United States needs to bring its own house in order, including its economic and education infrastructure, as well as its technical capabilities. These issues form the basis of all the questions covered in the last two days. All these conferences, observations, papers and reports that have been written will be for naught unless we begin to act constructively to deal with these issues.

APPENDIXES

A

Contributing Authors

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GEORGE GAMOTA was previously Chief Scientist for the MITRE Corporation's Bedford Group and is currently Director of the MITRE Institute. Before joining MITRE, Dr. Gamota was founder of Science & Technology Management Associates, President of Thermo Electron Technologies Corp., professor of physics and Director of the Institute of Science and Technology at the University of Michigan, Director for Research in the Office of the Secretary of Defense, and a member of the technical staff with Bell Laboratories. Dr. Gamota also participated in several studies, missions, and task forces that served in an advisory capacity to various government agencies. He holds a Ph.D. in physics from the University of Michigan and is the principal author of *Gaining Ground* , a book describing Japan's strides in science and technology.

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DALE W. JORGENSON is currently Frederic Eaton Abbe Professor of Economics at Harvard University and Director of the Program on Technology and Economic Policy at the Kennedy School of Government. He also taught at the University of California, Berkeley, and was visiting professor at Stanford University and the Hebrew University of Jerusalem. Dr. Jorgenson is coauthor of *Tax Reform and the Cost of Capital*, as well as managing editor of the monograph series *Contributions to Economic Analysis*. A recipient of the John Bates Clark Medal of the American Economic Association, Dr. Jorgenson holds economics degrees from Reed College and Harvard University and is a member of the National Academy of Sciences.

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G. LAURIE MILLER has been head of the Interactive Systems Research Department (formerly Robotics Research Department) at AT&T Bell Laboratories since 1982, where he specializes in instrumentation, robotics, sensors, and measurement. He holds over 30 patents in his field, and is the author of numerous publications. Dr. Miller received a bachelor's degree in physics, a master's degree in mathematics, and a Ph.D. in nuclear physics, all from the University of London. He is a fellow of the American Institute of Physics as well as a fellow of the Electrical and Electronic Engineers.

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HIROSHI OTA was Director-General for Scientific and Technological Affairs for the Japanese Ministry of Foreign Affairs prior to being appointed Japan's ambassador to Saudi Arabia in 1992. During his career with the ministry, Mr. Ota has served as Deputy Director-General of the Economic Cooperation Bureau, Deputy Director-General for General Affairs in the Economic Affairs Bureau, Director of the Scientific Affairs Division and the Policy Planning Division, as well as in various positions at the Japanese embassies in Korea, the United States, and the United Kingdom. He is a graduate of the University of Tokyo and earned an M.A. in international relations from the Fletcher School of Law and Diplomacy.

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DAVID J. TEECE is Mitsubishi Bank Professor, Walter A. Haas School of Business, and director of the Center for Research in Management at the University of California, Berkeley. Prior to joining the Berkeley faculty, Dr. Teece was associate professor of economics at the Graduate School of Business at Stanford University. Having a strong interest in innovation, technology strategy, science and technology policy, and antitrust, he has written extensively on industrial organization, corporate strategy, and public policy. Dr. Teece received a B.A. and M.Comm. from the University of Canterbury and M.A. and Ph.D. degrees in economics from the University of Pennsylvania.

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B

Conference on Japan's Growing Technological Capability: Implications for the U.S. Economy

October 23 and 24, 1991—Lecture Room

National Academy of Sciences—Washington, D.C.

National Research Council

Committee on Japan

WEDNESDAY, OCTOBER 23, 1991

Registration and Coffee

Opening Remarks by Chairman

C. FRED BERGSTEN, Institute for International Economics and Member, Committee on Japan

Technology Assessment in the U.S.-Japan Context

GEORGE GAMOTA, MITRE Institute

JIM MARTIN, Rockwell International

SHIGETAKA SEKI, Ministry of International Trade and Industry, Agency of Industrial Science and Technology

Open Discussion

Lunch

Impacts and Implications for the U.S. Technology Base

Macro Issues

DALE JORGENSON, Harvard University

MASARU YOSHITOMI, Economic Planning Agency of Japan

Open Discussion

Micro Issues
WILLIAM FINAN, Law & Economics Consulting Group
DAVID TEECE, University of California, Berkeley
Open Discussion
Adjourn
THURSDAY, OCTOBER 24, 1991
Registration and Coffee
Future Scenarios: Japan, Technology and Competition in the 21st Century
JOHN CANTWELL, University of Reading
FUMIO KODAMA, National Institute of Science and Technology Policy
EDWARD GRAHAM, Institute for International Economics
Open Discussion
Policy Implications for the United States
RICHARD NELSON, Columbia University
Comments
ERICH BLOCH, Council on Competitiveness
HIROSHI OTA, Foreign Ministry of Japan
Open Discussion
Closing Remarks by Chairman
C. FRED BERGSTEN
Adjourn